building successful HF ANTENNAS

By Peter Dodd, G3LDO

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Radio Society of Great Britain

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Introduction

In the early days of amateur radio most equipment was home made. The attitude at the time was that building equipment and antennas was an essential part of amateur radio; furthermore commercial equipment was scarce and expensive. These days we have more bands and modes than ever before, resulting in radio equipment becoming more complex. This, together with lower manufacturing costs, has resulted in a amateur radio scene dominated by commercial equipment.

Antennas, on the other hand, have changed very little. Because of their relative simplicity, we can all build antennas, quite often from materials found in a DIY store. I write the 'Antennas' column for the RSGB journal *RadCom* and most of the questions I receive from readers are concerned with the practical aspects of antenna construction. The purpose of this book is to address this perceived need.

Almost all queries regarding antennas are concerned with HF antennas. For this reason it was decided to restrict the book to this area; VHF and UHF antennas are dealt with in *VHF/UHF Antennas*, by Ian Poole, G3YWX (RSGB).

The first chapter describes, in general terms, what makes a good antenna, and the importance of providing an optimum location within the constraints of your location.

The classification of the antennas shown in the next two chapters may seem rather unconventional. The reason for this is that many amateurs, mostly newcomers, have bought a rig and want a simple wire antenna to get on the air, and these are described in Chapter 2. If you have invested in an Antenna Tuning Unit (ATU) there is a much larger selection of wire antennas available to you as described in Chapter 3.

Commercial and home brew ATUs are covered in Chapter 4. Construction of fixed beam antennas, Yagis, quads and loop antennas covered in the next four chapters with new material on feeding the multi-band quad

I am often asked for practical advice on where to find and how to use material for antenna construction using, where possible using materials found in DIY stores. This is covered in Chapter 9, while solutions to the all-important problem of supporting your antenna high enough to become effective is described in Chapter 10.

Although antenna theory has generally been avoided in this book a small amount of transmission line theory has been included to explain SWR in Chapter 11. Finally, methods of estimating and checking the performance of an antenna during or after installation are covered in the last chapter.

Finally, I would like to thank all those whose published work helped to make this book as comprehensive as it is. Details are shown overleaf.

Peter Dodd, G3LDO
August 2008

ACKNOWLEDGEMENTS

The source of a publication is referenced at the appropriate point within the text, however the scope of the referenced material is given below.

Articles and Columns

'Fitting Coaxial Connections', Roger Blackwell, G4PMK, *RadCom* May 1988.

'Balanced to Unbalanced transformers', Ian White, G3SEK, *RadCom*, December 1989.

'Taming the End-Fed Antenna', Alan Chester, G3CCB, *Radcom*, September 1994.

'A Remote Controlled ATU', L B Uphill, G3UCE, *Radcom*, February 1989.

'A General-Purpose Antenna Tuning Unit', M J Grierson, G3TSO, *RadCom*, January 1987.

'Optimum Ground Systems for Vertical Antennas', John Stanley, K4ERO, *QST*, December 1976.

'An improved Z-match ATU' by Louis Varney CEng MIEE AIL, G5RV, *Radcom*, October 1998

'Experimental Magnetic Loop Antenna' C R Reynolds, GW3JPT, *Radcom*, February, 1994.

'The HF Skeleton Slot Antenna', Bill Capstick, *Radcom*, June 1996.

'Roof-space dual band magnetic loop', Eric Sandys, GI2FHN, in Technical Topics column by Pat Hawker, G3VA, *RadCom*, February 1993.

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Material from the following RSGB publications has been used in this book and is referenced in text where appropriate.

Practical Wire Antennas, John D Heys, G3BDQ.

The Radio Amateur's Guide to EMC, Robin Page-Jones, CEng MIEE, G3JWI.

HF Antennas for all Locations, L A Moxon, G6XN.

LF Today, Mike Dennison, G3XDV.

The Antenna Experimenter's Guide, 2nd edn, Peter Dodd, G3LDO.

RSGB Planning Application Booklet

1

The antenna and its environment

When you say that your antenna is working poorly or working well, what exactly does this mean? It might be that you can hear other local stations working DX stations that you cannot hear or work, and you then assume (rightly or wrongly) that the antenna is working poorly. On the other hand if you manage to work some DXpedition through the pile up you conclude that the antenna is working well.

To some degree how well an antenna is working is bound up with your expectations. If you buy an antenna for which the sales blurb makes a lot of claims and the antenna, in your opinion, does not meet these claims then you conclude that the antenna is working poorly. If, on the other hand, you fix a length of wire into the loft and work quite a lot of countries while testing it out you might feel that the antenna is working well.

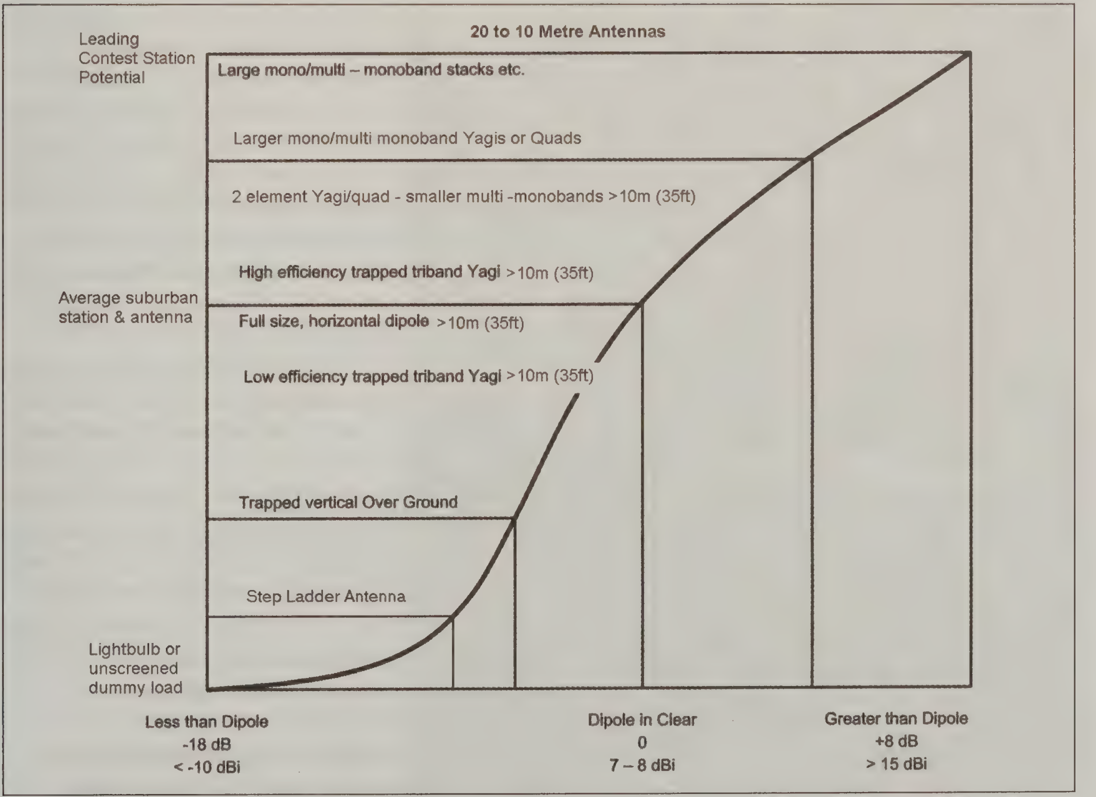

Fig 1.1: N6BT's edited graph of antenna performance.

Thomas Schiller, N6BT, writing in *QST* [1] claims "Everything Works" and demonstrates the point by having contacts using an antenna comprising nothing more than a light bulb fixed on top of a short pole. He also produced a graph, see **Fig 1.1**, showing what you might expect from various antennas (including the light bulb) in various locations. One thing that you will notice is that the dipole performs quite well on this graph.

I write the 'Antennas' column for *RadCom* [2] and in June 2006 became involved in the 'Strange Antenna Challenge' hosted by Erik Weaver, N0EW [3]. The idea of the challenge was simple: Construct an antenna from something that is not normally used as an antenna. Antenna materials used in previous challenges have included such items as metal folding chairs, shopping trolleys, chicken wire, fences, ladders and trucks.

Antennas constructed of wire or metal pipe or tubing (normal antenna materials) are NOT permitted. Feeder is permitted but efforts must be made to prevent the feeder from radiating by using current chokes or baluns if using coax, or a balanced feed if using twin feeder.

Inspired by this, I constructed an antenna from two step ladders and placed them on a garden table as shown in **Fig 1.2**. The two ladders were fed as two elements of a dipole using a two metre (6ft) length of 400-ohm ladder line feeder (no pun intended!). The 'antenna' exhibited a broad resonance at about 23.5MHz with a feed impedance of around 12 ohms at resonance. The antenna was tried on several bands and loaded on all HF bands, 10MHz and up. This arrangement worked well using SEM Z-match and an IC-706Mk1on CW.

Contacts were no more difficult than working with QRP (less than 5 watts) into a 'normal' multiband dipole antenna, 10 metres (30ft) high . In just over an hour I made five QSOs around Europe and on average my reports were about two S-points down on the ones I gave out. In this case my expectations were not high and I felt that the antenna was working well.

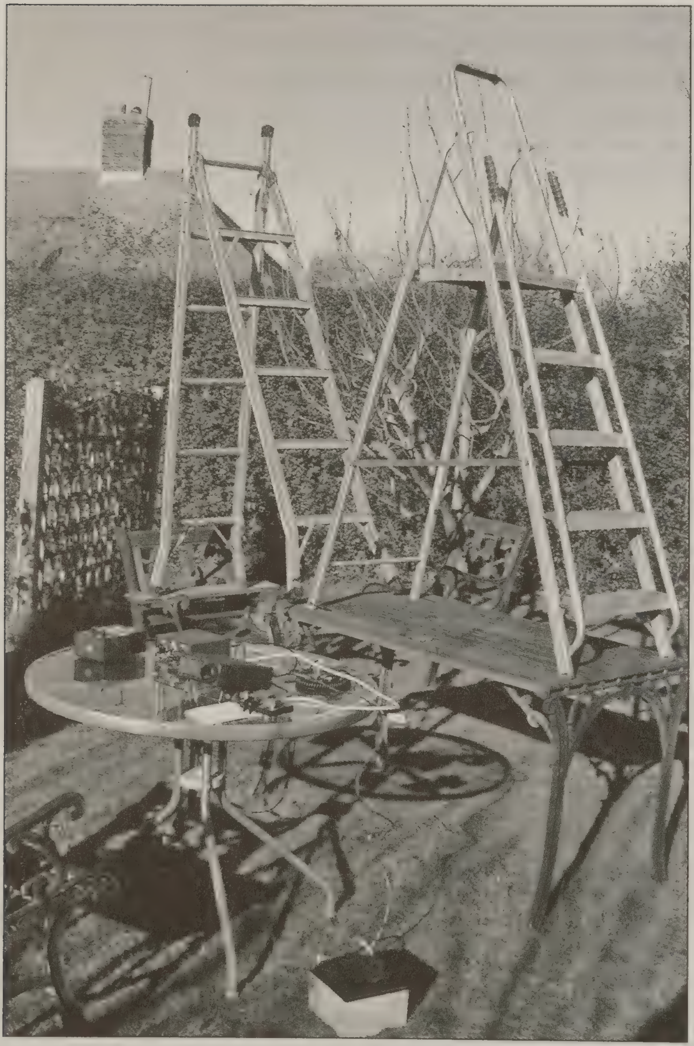

Fig 1.2: An experimental antenna for HF using two step ladders.

The antenna was then moved to the flat roof of the house extension, thereby increasing the height from 0.8m to 3.2m (3ft to 10.5ft). The resonance was about the same and the feed impedance increased to 16 ohms. This move improved the performance so that the average signal strength difference between what was received and what was given was less than one S point. I even managed to work a couple of east coast USA stations during the short test period.

The purpose of this exercise was to show that any metal structure can be made to radiate provided it can be persuaded to accept RF power from a transmitter. How well it radiates this power depends on where the antenna is placed. Because of the reciprocal nature of the antenna its placing also determines how well it receives.

I have been asked, usually by those who live in restricted locations, if certain compact commercial antenna products will solve their antenna problems. I reply that in many cases a simple wire antenna suitably placed and suitably fed will out-perform them even in the most restricted of locations. I proposed an experiment in the form of a competition to construct the cheapest of all antennas - a 15m (50ft) piece of wire. The objective was to see how many stations could be worked using the antenna, over a period of 50 days from 1 September to 20 October 2002.

The antenna wire could be any diameter up to 2mm, and fed at any point using any length of feeder, but the feeder must not be part of the radiating system. The antenna could be re-orientated during the test period as part of the experimental process.

Peter Cole, G3JFS, made 1248 QSOs with 139 countries. Contacts were made using a 15m end fed wire hung from trees at the bottom of his garden. The antenna, used for quick band hopping, was tuned by an SG230 Smartuner situated in a garden shed. About 18m (60ft) of buried low loss 50 ohm coax and control wires are used between the shed and the upstairs shack. The first 9m (30ft) of the antenna wire sloped northwards from the shed to about 7.5m (25ft) and the remainder sloped west to east up to 9m (30ft).The earth system used quite a lot of wire buried in the ground as well as fence wires on two sides of the garden.

G3JFS used an IC706 for QRP operation (5 watts) and an FT990 and FT1000 (100 watts) using CW, SSB, RTTY and PSK31. The total number of contacts was enhanced by casual operating in the large number of contests during the period of the test. However a lot of the contacts were 'proper' QSOs of 10-30 minutes.

G3JFS noted that he had been asked many times for advice on what antenna to use. His usual recommendations for a restricted site are:

1. Put up the longest bit of wire you can and centre feed it with open wire line.
2. Put up a half wave dipole for one of the HF bands and find out what you can do with it.
3. As a last resort use an end-fed wire on the lines of the W3EDP antenna, preferably with quarter wave counterpoise wires for the various bands of interest.

He went on to say that his preference for a simple wire antenna is a doublet with provision to change its length on the higher bands to go from a multi-lobe to figure of eight pattern. On the LF bands it can be used as a 'T' with the feeder strapped. The end-fed wire plus the Smartuner is generally weaker but is very convenient.

HF PROPAGATION

A basic knowledge of HF propagation pays dividends when planning an HF station and antennas.

All signals outside of ground range are propagated over large distances by being refracted via ionised layers of the ionosphere. The most important of these layers is the outer one, known as the F2 layer. This layer, located around 300 to 400km high, is responsible for most of the long-distance HF communications.

When a signal is transmitted over a certain path there is a maximum frequency which can be used. As the transmission frequency is increased, the signal penetrates further into the ionospheric layers until it passes straight through and escapes into outer space as shown in **Fig 1.3**.

The highest frequency that can be refracted is known as the MUF (Maximum Usable Frequency) and is dependent on the density of the ionised layer. This density depends on the amount of radiation being received from the sun so it follows that the MUF highest during the hours of sunlight and decreases dramatically at night.

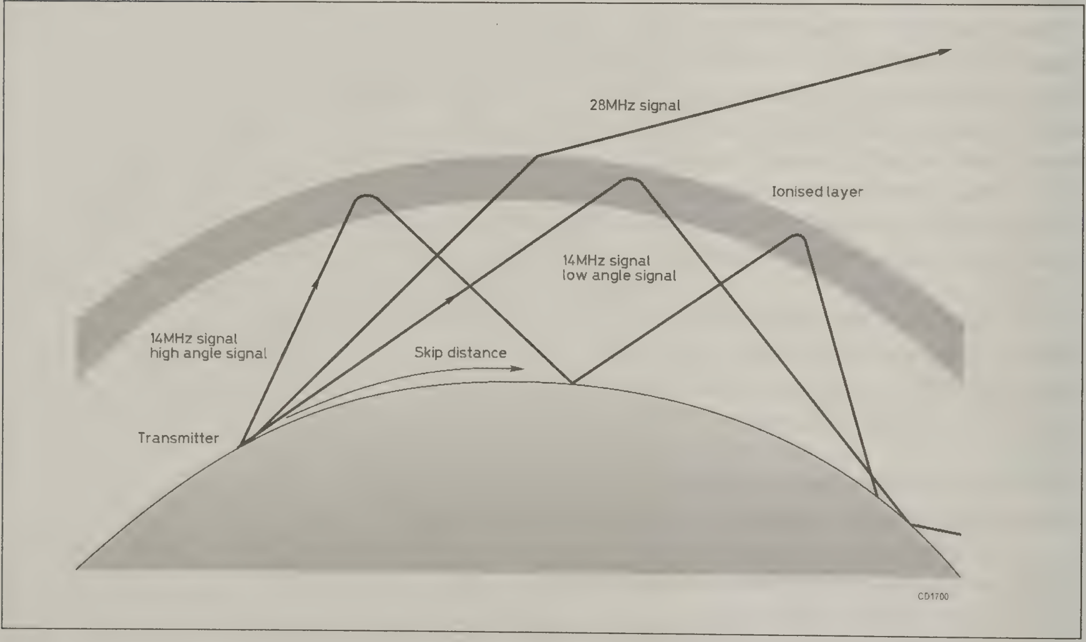

Fig 1.3: A very simplified diagram of the ionosphere and radio propagation where the MUF is around 20MHz. Signals on 14MHz radiated from a transmitter are propagated by refraction from the F2 layer. In practice the signal may make several skips before arriving at a distant receiver. The 28MHz signals are higher in frequency than the MUF and pass through this ionised layer.

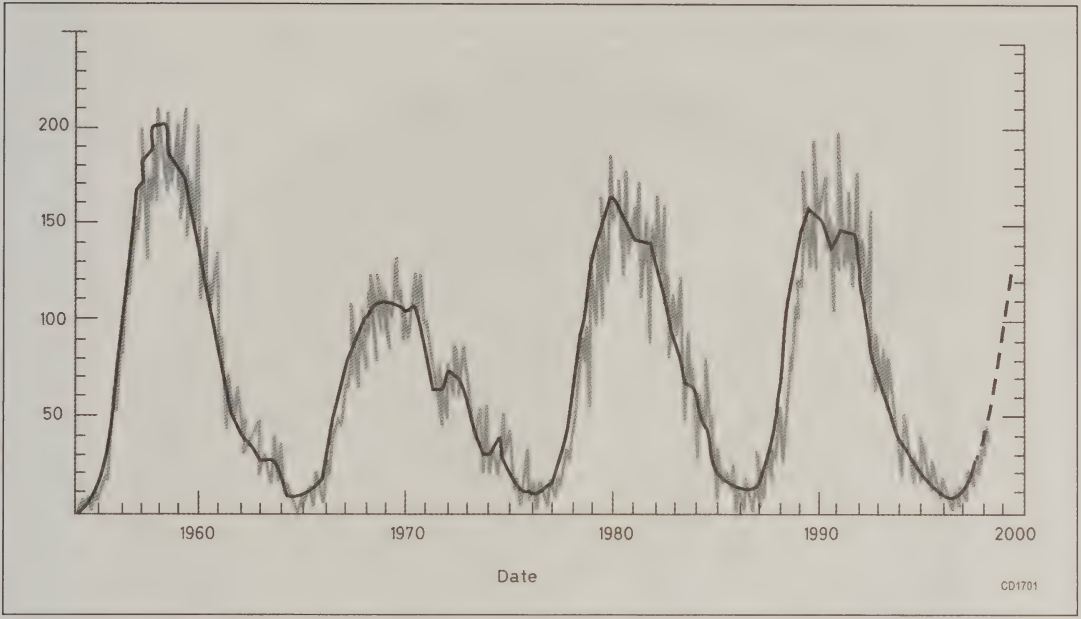

Fig 1.4: Sunspot cycles from 1959 to 1998. The day-to-day numbers of sunspot activity vary widely. In order to view the trends the data is averaged over a month (shown in the grey lines) or smoothed over a wider period (shown by the black line).

The radiation from the sun causing ionospheric density is greater during periods when sunspots are visible on the sun. These areas of the sunspots vary and have cyclical variation with a period of about 11 years as shown in **Fig 1.4**.

The smoothed data enables us to make predictions, which can be used to predict the future sunspot number. The dashed line predicted a smoother sunspot number of around 120 for the year 2000. Compare this with a more up to date sunspot record shown in **Fig 1.5**, which shows that the sunspot cycle did reach that figure at that date.

At one time solar activity was measured by a complex method counting the 'sunspot number'. A more reliable method has been devised by measuring the level of solar noise. This is normally measured at 2800MHz (a wavelength of 10.7cm) and is called the solar flux, and is closely related to the daily sunspot number.

At the low point of the cycle, the high frequency bands above 20MHz or so may not support ionospheric refraction, whereas at the peak of the cycle frequencies at 50MHz and higher may be propagated. You may like to use the predictions in Fig 1.5 as a consideration in planning your next antenna installation.

A more representative (but still simplified) diagram of the ionosphere, see **Fig 1.6**, shows the ionosphere to be far more complex than shown in Fig 1.3. These layers are designated 'D', 'E', 'F1 ' and 'F2'.

The D layer is the lowest of the layers of the ionosphere. It is ineffective in bending HF signals back to earth and only attenuates signals passing through it. This attenuation is low at the higher HF frequencies but very high at the lower HF frequencies. At night the D layer disappears; this explains why the lower HF frequencies give better propagation at night.

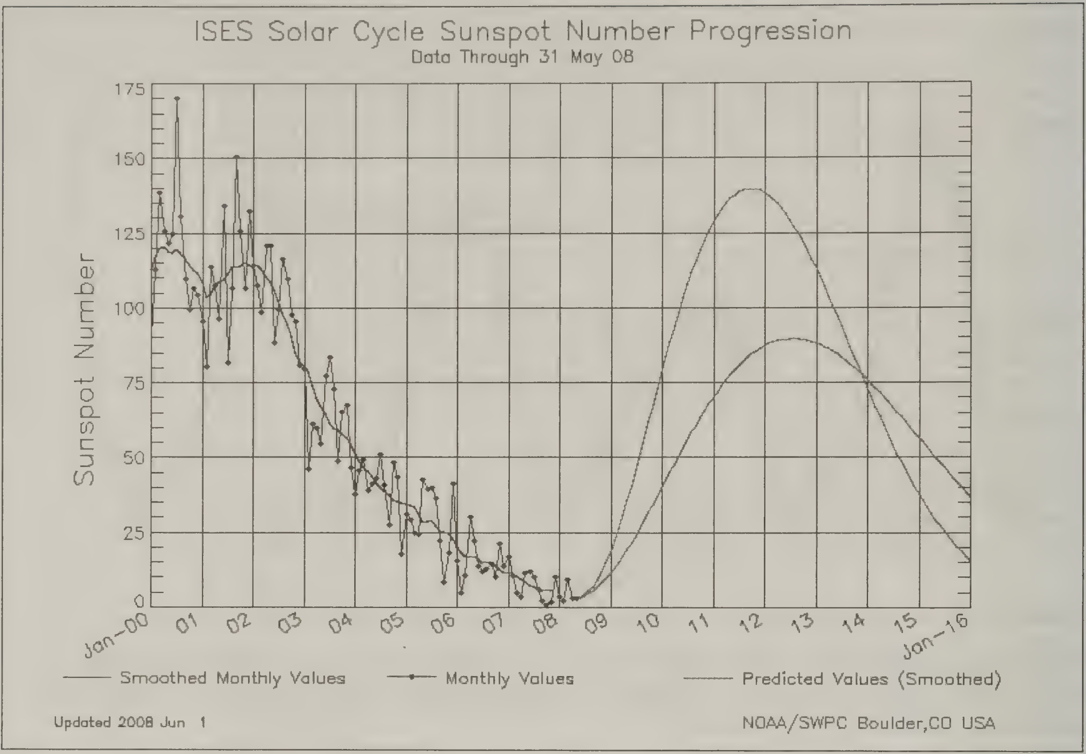

Fig 1.5: Sunspot cycle from 1996 to June 2008 and the prediction for sunspot cycle 24. You will notice two prediction graphs. The large and small graphs are the smoothed high prediction and the smoothed low prediction forecasts respectively. Sunspot number and solar flux are closely related.

The role of the E layer is more complex; partly absorbing and partly propagating radio signals.

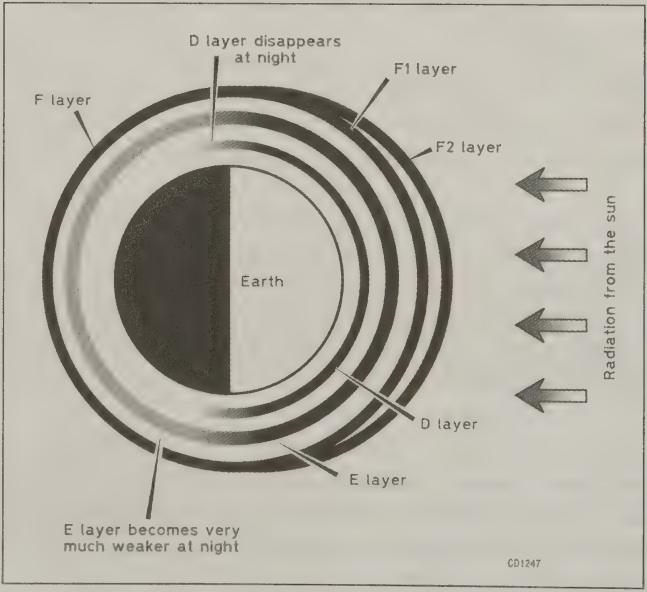

Fig 1.6: Simplified view of the layers of the ionosphere over the period of a day. Although the F layer remains intact at night its density decreases and the MUF may only allow propagation on 80 or 160 metres.

These lower level ionised layers mean there is a lower limit to the range of frequencies that allow radio propagation between two distant locations. The point where the signal becomes unreadable is known as the Lowest Usable Frequency (LUF). The LUF increases in periods of high solar activity because increased

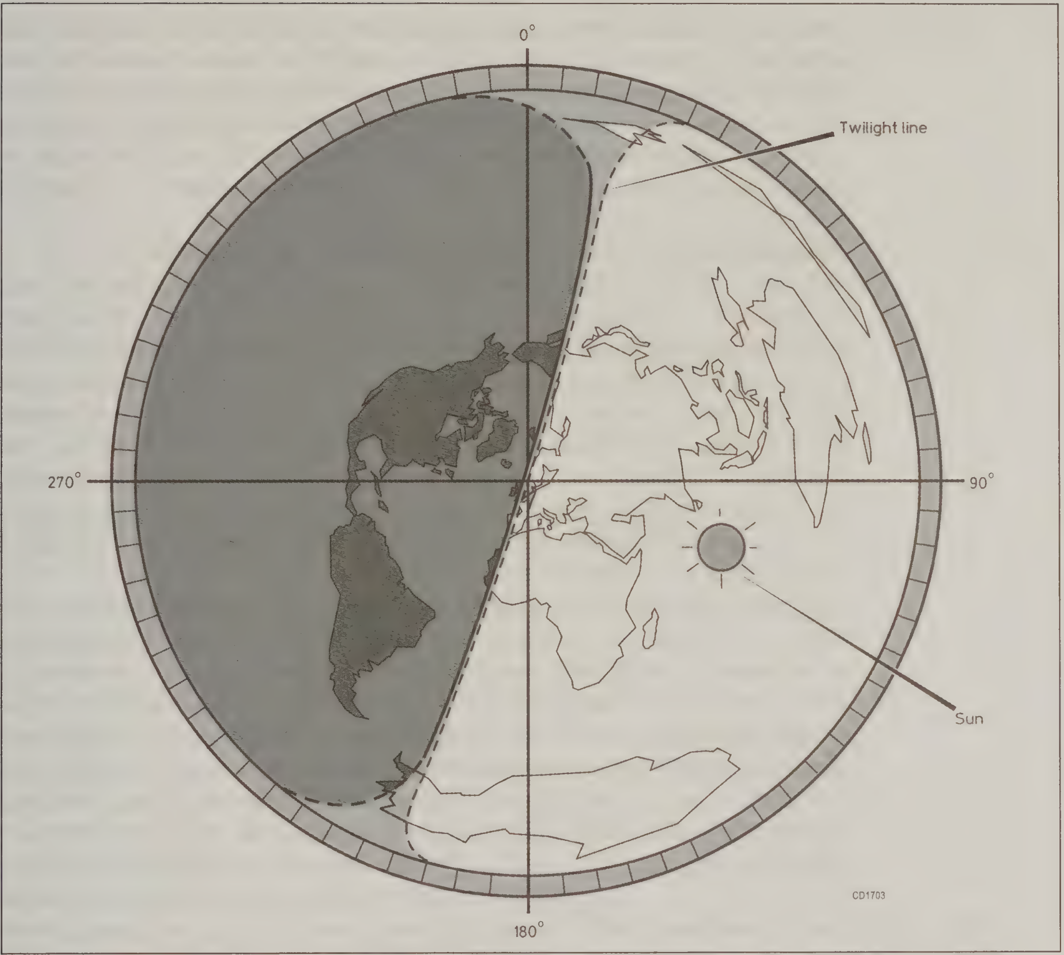

Fig 1.7: Great circle map of the world (showing direction and range from the UK) with the grey line path to New Zealand at 0800UTC in mid February 1999.

radiation from the Sun increases the D layer ionisation and hence its absorption. Sometimes the LUF is higher than the MUF; under these circumstances there is no propagation at all and the band(s) are 'dead'.

In general, higher frequencies give the best results for smaller antenna installations. This is because the effect of attenuation by the D layer is reduced. Although signals may pass through the D layer they still suffer some attenuation as already mentioned. As losses are incurred at each reflection hop, either at the ionosphere or at the Earth, the minimum number of reflection hops is desirable.

The best time to contact stations on the other side of the world is when the D layer is non-existent or relatively weak and the F layer is dense enough to sustain radio propagation. This phenomenon normally occurs around sunrise and several hours after, and in the evening, depending on the solar flux and the frequency in use. If you are interested in this type of DX operation it is useful to know the paths on which this propagation occurs at your location. An example of this twilight 'grey line' path is shown in **Fig 1.7**

The angle at which the signal leaves the antenna and travels towards the ionosphere is defined as the angle of radiation, the angle between the main lobe of the signal and the horizon. The low angle signals shown in Fig 1.3 travel much further in a single hop than the high angle ones. Even a relatively small increase in the angle of radiation can considerably reduce the distance covered in one hop. The maximum distance that can generally be achieved using reflection from the F-layer, is considered to be 5000km (3000miles). This is reduced to just 1000km if the angle of radiation is 20 degrees. The angle of radiation depends on where the antenna is placed and how it is orientated.

Translating basic propagation forecasts

Although solar flux and sunspot activity may be used to predict the HF bands you might use, the short-term conditions are much more complex. Although not related to antenna planning and construction the following simplified G3ENI, [4] method of translating basic propagation forecasts has been included to complete the picture. Amateurs who have been active for many years over several sunspot cycles often develop an instinct for judging band conditions. Routine checking of DX broadcasting stations on adjacent bands is often helpful, as are the 28MHz worldwide and 14MHz sequential beacons. However, it is possible to carry out basic forecasting oneself to supplement and update the propagation information from the RSGB [5].

Ignoring the multiplicity of solar events, which cause variations in the ionosphere, we need to consider two main items: Firstly, the 'solar flux' which is noise measured on 2800MHz each day and which ranges from a minimum of about 66 units to a maximum of about 300 units (good conditions on the higher HF bands require a high flux); secondly, 'geomagnetic activity', which acts against the benefits of high flux and may be presented as either 'A' or 'K' units.

Solar flux and geomagnetic activity data can be found on various websites; for example [6]. **Fig 1.8** shows, in approximate terms, the relationship between solar flux and geomagnetic activity to determine expected propagation conditions. On the chart, solar flux is plotted vertically. The geomagnetic index is shown horizontally with the two scales: the K scale is based on readings taken eight times a day, each covering the previous three hours. The A scale is based on the eight K values for the previous day. The intersection of the flux and geomagnetic activity values determines the expected conditions, divided into eight zones as given in the caption.

At times the Earth's magnetic field is affected by solar activity. These geomagnetic disturbances often result from

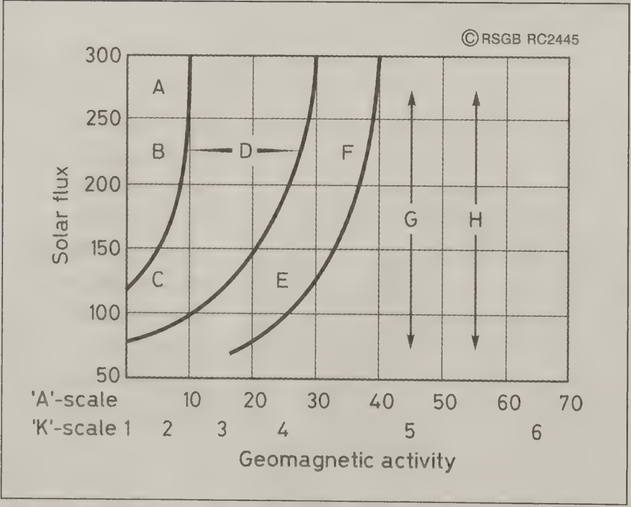

Fig 1.8: Chart relating solar flux and geomagnetic activity to likely band conditions as published by G3ENI in the *TVARTS Newsletter*. Zone A: Above normal 50MHz open, 21 to 28MHz open up to 24 hours. Zone B: Above normal, 21 to 28MHZ open up to 24 hours. Zone C: 21 to 28MHz alive. Zone D; Normal conditions. Zone E: Below normal, unsettled. Zone F: Below normal, disturbed. Zone G: Disturbed, substorm level, auroras may form. Zone H: Storm level, auroras.

bombardment of low-energy particles from the Sun. In turn this can result in an ionospheric storm which can disrupt communications on the HF bands. It is given in the form of two indices. The first is called the K index. This is measured on a scale between 0 and 9 where 0 is the quietest and 9 indicates the most disturbed. It is based on values measured at several points around the Earth and is updated every three hours.

Another index called the A index is also available. This can vary between 0 and 400. However, the A index is in a twenty-four-hour form and is therefore less immediate than the K index. A conversion between the two indices is given in **Fig 1.8**.

The Sunspot Index Data Centre in Brussels prepares the numbers from information supplied by a number of observatories. They appear in DX propagation information available from a wide variety of sources including the RSGB [5, 6]. The 12-month smoothed sunspot number correlates quite closely with the prevailing HF radio propagation conditions.

THE ANTENNA AND ITS ENVIRONMENT

Before constructing an antenna it might be useful to consider the environment of your proposed antenna and what sort of operating you want to do. Most of us live in suburbia. Operating an amateur radio station from a suburban location imposes many limitations that can be best overcome when you understand them.

Each of the HF bands has different characteristics depending on sunspot activity, season and time of the day. If you work for a living and can only operate in the evenings or weekends then the upper HF bands may have limited value and wider multiband operation is often necessary.

Also, there are often contests on at weekends on the main frequency bands but not the 'WARC' bands (10, 18 and 24MHz). If you can only operate during weekends then this may influence which bands you use.

Retirement gives the opportunity for operating at any time. Some operators in this category concentrate on a single band using a beam antenna.

It is often the case that the situation creates the interest - a persistent case of TVI or BCI causes the operator to try low power operation, or the difficulty in finding space for an HF antenna causes the operator to discover VHF/UHF satellite operation, particularly if he lives on high ground.

Improving antenna effectiveness

Some years ago I knew a recently licensed amateur who decided to put up a simple horizontal dipole so that he could make a start. He connected the one end of the dipole to the eaves of the house and the other to an extension of the washing line post at the bottom of the small garden as shown in **Fig 1.9**. This gave the antenna an average height of around 4m (15ft).

The antenna performed to his satisfaction with good reports from all over Europe, the Middle East, North Africa and the USA; and soon he was working towards a DXCC award. However, the signals from greater distances were proving more difficult because they were weak and because of the QRM from the very strong near by European stations. He also experienced interference from domestic electrical devices and suffered breakthrough on his neighbour's bedroom television.

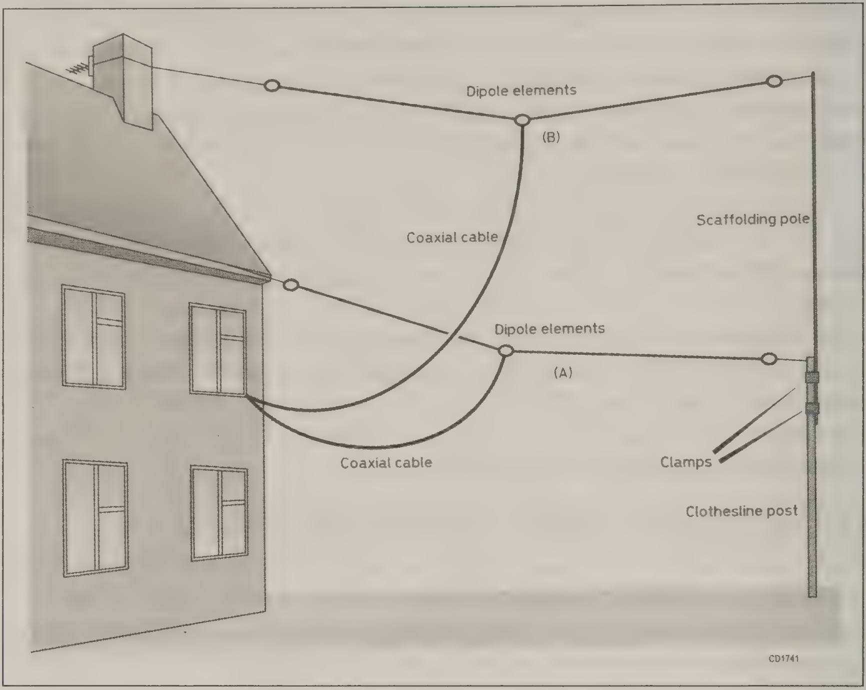

Fig 1.9: Antenna (A) shows a quick fix installation for a 14MHz dipole placing it, say, around 7m (22ft) high. With the minimal effort the dipole height (B) can be raised substantially to around 11m (30ft) high.

I suggested fixing one end of the dipole to the chimney and the other end to a taller pole at the bottom of the garden, raising the average height to, say, 10m (30ft), see Fig 1.9.

The reason for this suggested increase in height is to lower the angle of radiation. The improvement in performance achieved by repositioning the dipole is illustrated in the computer model shown in **Fig 1.10**

As discussed earlier under HF Propagation, you can see that the long distance signals arrive at the antenna at an angle of less than 20 degrees. From Fig 1.10 it would seem that the modest increase in height would give an increase in gain to DX stations of 2dB while at the same time reducing the short skip signals by about 4dB.

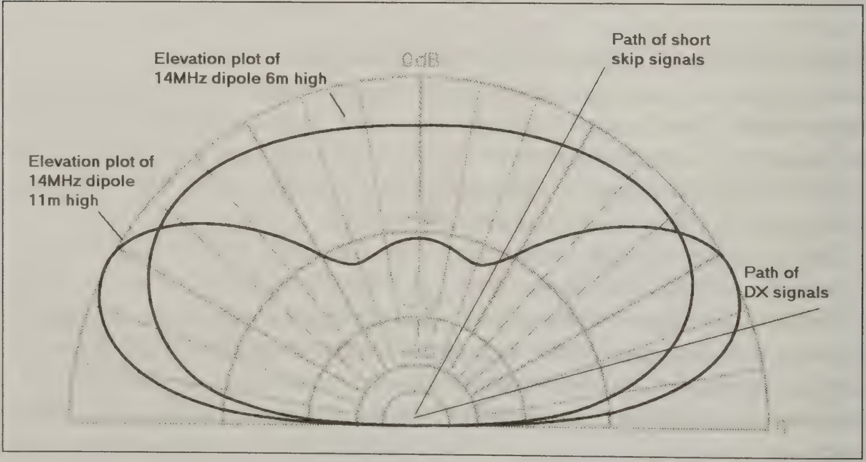

Fig 1.10: Elevation radiation pattern for 14MHz dipoles at different heights above ground shown in Fig 1.9.

LOCATION, LOCATION

It is all very well me saying that you have to position the antenna as high as possible to have successful DX contacts. However, most of us are restricted to suburban lots, which we have to live with.

I will consider a number of different types of typical locations and suggest possible antenna solutions. Where a solution is general, a reference will be made to suitable antennas described in following chapters. If the solution is specific then it will be described under the location heading.

Rather than describing a 'dwelling' as a location for an antenna, I have considered the type of location. For example, a long narrow garden could be associated with older terraced houses, or two-story flats, where the gardens are partitioned off into thin strips. Likewise, a suitable loft may be found in any house, bungalow or multi-story flat.

A map of your house and the garden can be useful when trying to consider which antenna or antennas you use. Mark out the size and location of the house and any trees. It is useful to make the drawing on graph or quadrille paper with the squares being related to whatever units of measurement you are comfortable with.

Overhead AC supply cables are fortunately rare in suburban locations. However, if you are unfortunate enough to have these obstructions, it is very important that antennas are positioned so that they cannot possibly come in contact with them.

Wire antennas and dipoles can be bent into all sorts of shapes. Although this may affect the resonant frequency of a resonant antenna (such as a dipole) it will not seriously affect the performance provided the bends are not too extreme.

Long narrow garden

For the HF bands any of the wire antennas described in Chapters 2 and 3 are suitable. Most older houses have a chimney so a short mast fixed with a chimney bracket, as described in Chapter 10, will make a good support of one end. A length of scaffolding pole can be used the opposite end, although a small version of the self-supporting fold-over mast, also described in Chapter 8 would be suitable.

The gardens of these types of dwelling are usually too narrow for a guyed mast. Small antennas can be fixed to the chimney or to the wall on a small mast (but check the condition of the brickwork if the house is old) as described in Chapter 10.

Small garden

A small garden associated with either a semi-detached house or bungalow is usually rectangular and may be large enough to erect a fold-over mast as shown in Chapter 10 and fit a small HF beam with a rotator. An HF wire antenna will probably have to be bent in more than one place. If the dwelling has a chimney, it should be pressed into service as an antenna support as described in Chapter 10.

If any of the HF antennas described cannot be erected then consider the large multiband delta loop described in Chapter 8. This type of antenna works very well as a transmitting antenna but is prone to electrical interference. In this case the antenna can be used with receiver loop antenna located some distance from the house.

Lofts

Most dwellings in the UK have a loft. Normally the loft is an unused part of the house and is used for storing junk. All modern houses have a layer of roofing felt under the roofing tiles and the area is relatively dry and weatherproof. The advantage of loft antennas is that they do not need weatherproofing. In addition there are numerous wooden beams that can be used to support the antenna using cheap TV antenna fittings.

The disadvantage is that they may be located close to electrical wiring with the possibility of mutual interference. There may be another disadvantage.

I once lived in an old town house in Harrogate that was in the centre of a row. It had no garden but it had four floors so the roof was quite high. Not long after moving in I ventured into the loft, which was festooned with black cobwebs, and was overjoyed to find that there was no wall in the loft between my house and my neighbours either side. There was enough room up there for a real antenna farm.

I started, modestly enough, with a 14MHz dipole. I fired up the rig expecting to work the world and found my antenna to be almost useless. I felt that there must be some fault with the construction and replaced the dipole and the feeder but the antenna performance was still just as poor. I then draped the antenna out through the top bedroom window and its performance improved dramatically. The reason for the poor performance of this antenna inside the loft space is unknown. The tiles on this old house were of Welsh slate and so this may have been the problem.

I then constructed a ground plane antenna as shown in Chapter 3 and had it fixed outside to the, chimney (using a suitable clamp as described in Chapter 10) by a television antenna erection company. This antenna performed very well although I was restricted to 14MHz.

Nevertheless, I have used a loft antenna in a modern house with moderate success, which implies the roofing material does play a part in antenna effectiveness with this type of installation.

I would suggest that anyone contemplating an indoor or loft antenna make an electrically short loaded antenna (Chapter 3) or a loop (Chapter 8) and try the antenna inside and outside the building. Note any changes in performance on transmit and signals to noise on receive in these different locations. A HF multiband loop, designed specifically for lofts, is described in Chapter 5.

High rise apartment or hotel

The high rise apartment block is usually constructed using a steel girder frame, which can have a significant effect on antenna performance. If the apartment has a large balcony and/or you have access to the roof the high rise apartment this type of location can be an effective location for an antenna.

If you can obtain access to the roof then there are greater possibilities. The comudipole antenna, described in Chapter 3, is a solution to feeding a multiband antenna located on the roof of an apartment block. You can often hear really

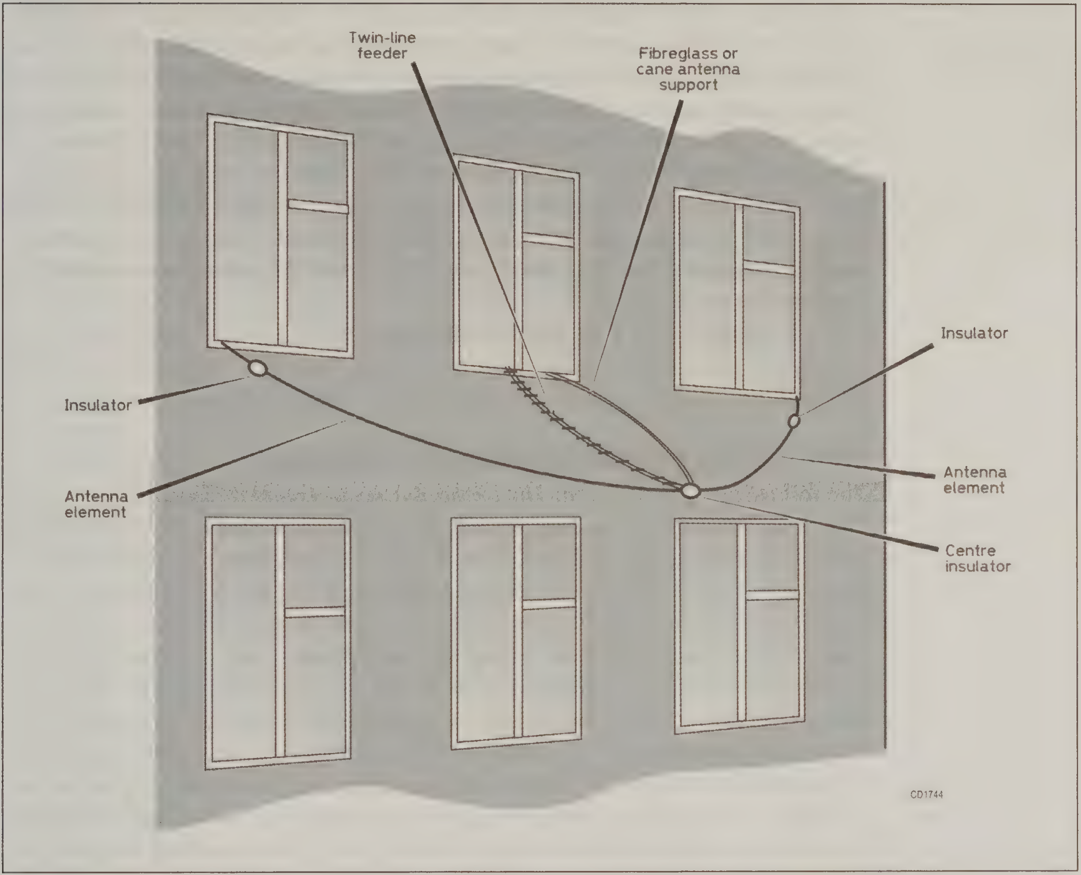

Fig 1.11: Construction of a multi-band dipole for the apartment dweller.

good DX signals from radio amateurs using a beam antennas on the roofs of a high rise apartments, particularly from Japan.

An alternative approach using the side of an apartment block is shown in **Fig 1.11**.

When working on antenna or antenna support systems on a high rise block balcony or rooftop pay attention to safety details. Not only should you not put yourself in danger; if you drop the smallest of tools or antenna fittings they can have a damaging velocity by the time they reach the ground. Tie all tools and fittings loosely together, with strong thin nylon cord, so that movement is not impeded but ensuring they don't fall far if dropped.

Locations with restrictive covenants

Many houses, flats and apartments now have covenants imposed on them by their deeds or tenancies, which prohibit the fixing of antennas of any kind to the structure of the building or in the garden. The first thing to do is to find out if such covenants are legally enforceable. If they are don't give up, there are a few tricks that can be used to circumvent the system.

Firstly, find out what is allowed. Are you allowed a flagpole? Are you allowed trees? For HF you can make either of these items into a vertical antenna as described in Chapter 3.

If you have an existing tree or similar support, an end fed antenna (Chapter 3) made from 1.5mm enamelled copper wire is almost invisible. Instead of using insulators use lightweight strimmer cord, which is clear and has excellent insulating properties, so a noticeable insulator is not required. If you do not have an additional support other than the building then the large delta loop (Chapter 8), constructed from 1.5mm wire and supported by strimmer cord, may be a solution. You could also use lightweight nylon cord as a support but the insulating properties are not as good as strimmer cord. However, clear nylon toothbrush handles make excellent insulators, even at LF where the voltages on a transmitting antenna are very high.

A loft antenna is the ultimate invisible antenna.

EMC

Minimising interference on receive

The following advice is from *The Radio Amateurs Guide to EMC* [7]:

Interference reaches the receiver either by direct radiation or by a combination of conduction and radiation. This means that interference generated at any particular location is likely to travel at least part of the way by a path involving a conductor of some sort. As previously discussed, signals can travel considerable distances using electrical wiring as a transmission line. In effect the electromagnetic energy is propagated between the wire and earth, though the situation is so indeterminate that it would be unrewarding to attempt to analyse it in any depth. Depending on the conditions, the wiring will also radiate energy; in this aspect the wire usually acts as a grounded antenna. In engineering terms the situation is an untidy collection of unknown factors, but so far as the present problem is concerned the message is simple. Keep your receiving antennas as far away as possible from house wiring.

The rules for minimising interference are the same as for reducing breakthrough and the reasons are much the same. Good receiving antennas for the HF bands should, where ever possible, be:

(a) Horizontally polarised, as interference radiated from house wiring is predominantly vertically polarised.
(b) Balanced, because just as poorly balanced antennas give rise to radiation from feeders, they will also allow signals to be picked up by the feeders;
(c) Compact, so that neither end comes close to house wiring.

If it is not possible to locate the antenna away from electrical wiring, and interference is a problem, then the compact resonant loop described in Chapter 8, gives an improved performance on receive in the presence of electrical noise.

Minimising EMC problems on transmit

Electrical wiring, such as mains supply, telephone or other utilities, will clutter the vicinity of any amateur station. The general plumbing and central heating system can also cause an unpredictable effect to nearby antennas. A poorly sited antenna will couple RF into the electrical wiring causing EMC problems.

Try not to be persuaded by social pressures into using low, poorly sited antennas. This can cause breakthrough problems that sour local relations far more than fears of obtrusive antennas might have done. It may be possible to improve transmitter antenna effectiveness without substantially increasing the visual impact of the antenna.

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[2] The members' monthly journal of the Radio Society of Great Britain (www.rsgb.org).
[3] www.n0ew.org/k0s
[4] 'Technical Topics', *Radcom* April 1992, quoting John Pegler, G3ENI, in the monthly newsletter of the Thames Valley Amateur Radio Transmitters Society .
[5] www.rsgb.org/news/propagation.php
[6] www.eham.net/DX/propagation
[7] T*he Radio Amateurs Guide to EMC*, Robin Page-Jones CEng MIEE, G3JWI (RSGB).

2

Simple antennas not requiring an ATU

The simple antennas described in this chapter are easy to construct and can be very effective. These antennas do not require a separate Antenna Tuning Unit (ATU), but a transceiver with an internal ATU could be an advantage.

THE RESONANT DIPOLE

Of all antennas the half-wave dipole is the most sure-fire uncomplicated antenna that you can make.

In its basic form it is essentially a single band half-wave balanced antenna, normally fed in the centre with coaxial cable. The current and voltage in one half of the dipole is matched by those values in the opposite half about the centre feed point, see **Fig 2.1**. The halfwave dipole will also present a low feed impedance on its third harmonic, so a 7MHz dipole will operate on 21MHz, also shown in Fig 2.1. Dipole lengths for each band are given in Table A1 in Appendix 1.

In most cases the dipole is better than 95% efficient and because it has a low impedance feedpoint it can be connected to the transceiver via a length of 50 ohm coaxial cable without the need of an ATU. The elements can be bent, within reason, to accommodate space restrictions.

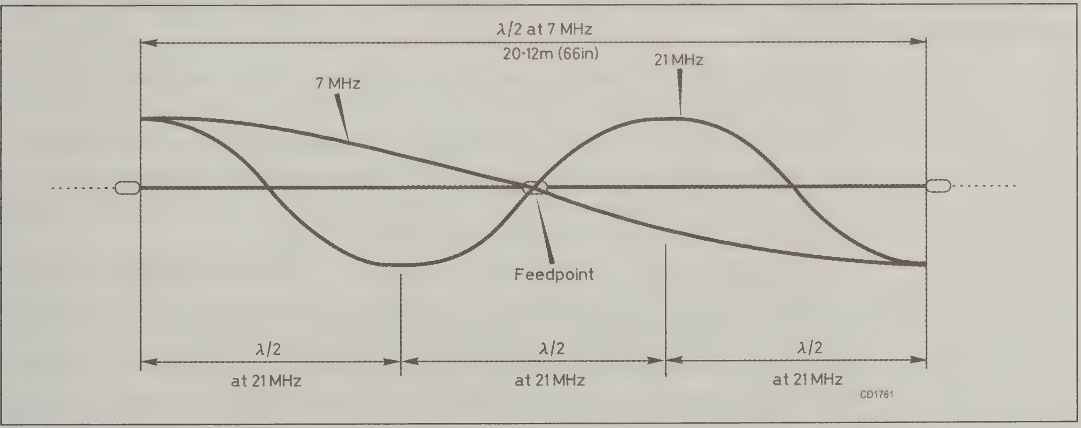


Fig 2.1: The voltage distribution on a 7MHz half-wave dipole. The coaxial cable is connected to the antenna at a point where the feed impedance is low (the voltage is low and the current is high). The 7MHz dipole will also have a low impedance at the centre on the third harmonic, at 21MHz.

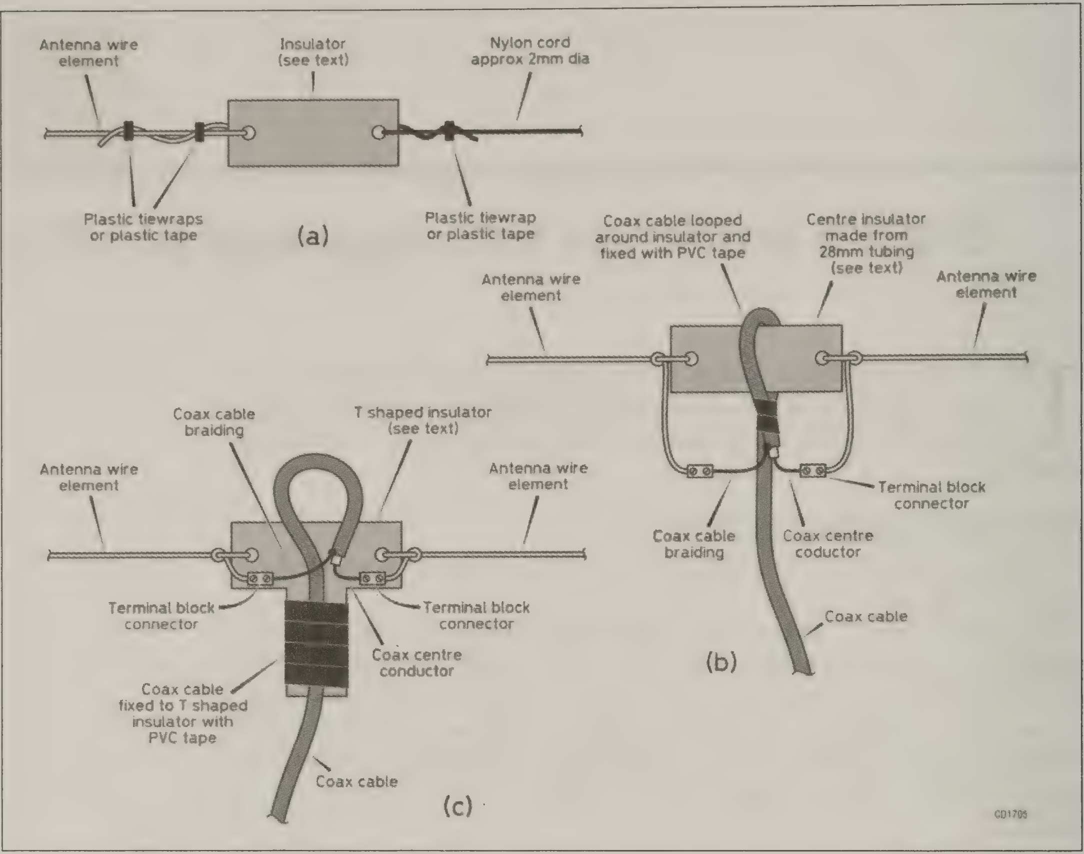


Fig 2.2: (a) A convenient arrangement for constructing a dipole so that the element lengths can be adjusted is to make the element longer than shown in Table A1 (in Appendix 1) and tape the excess back along the element. (b) Method of connecting coax cable to the centre of the dipole using a short length of tubing or a dog-bone insulator. (c) Method of connecting coax to the centre of a dipole using a specially constructed T insulator.

A practical dipole installation, with suggestions for optimising performance, is shown in Chapter 1.

There are various methods of connecting the coaxial cable to the antenna - two of these are shown in **Fig 2.2**. Both these arrangements take the strain of the coax from the connections. Also by having the ends of the coax cable facing downwards assists in preventing water entering the cable.

The weight of the coax cable can be significant. Unless there is a good reason for using heavy cable, for instance because you are running high power, it is best to use lightweight cable such as RG-58, or Mini-8, see Chapter 11.

The dipole can be supported using 2mm or 3mm nylon rope with 'dogbone' insulators at the ends of the elements. The method of connecting the antenna element to the insulator, shown in Fig 2.2, allows the dipole element length to be adjusted for minimum SWR.

DO NOT use egg insulators and wire as dipole element end supports - the end capacity of such an arrangement will cause some very unpredictable results; something I found out the hard way.

The dipole is described as a half wavelength antenna. In practice the dipole length is slightly shorter than half a wavelength because of end-effect. A true wavelength on 7.02MHz is 42.7m and a halfwave 21.35m. A halfwave dipole for the same frequency will be 20.78m (68ft 2in)

Dipole dimensions for each amateur band are shown in the Table A1 in Appendix 1, where the wire lengths have been calculated using EZNEC and assume the use of 2mm diameter wire and an antenna height of 10m (33ft).

Most antenna books use the formula 143/f (MHz) = L (metres) or 468/f(MHz) = L (feet). This gives a close enough approximation on the higher frequency bands but may be a bit short for the lower bands. For example the formula gives a dipole length of 40.6m for 3.52MHz while EZNEC calculates a length of 41.42m for the same frequency. Remember these lengths are total lengths and the wire has to be cut in half at the centre to connect the coax. You also need to be aware around 160mm (6in) at each end of each half of the dipole elements is required to connect them to the centre insulator and the end insulator

The 80 and 160 metre dipoles are quite long and should be made of hard drawn copper wire to reduce stretching and sagging due to the weight of the antenna and the coaxial cable.

The feed point impedance of a dipole at resonance can vary either side of the nominal 75 ohms, depending on height above ground, the proximity of buildings and their electromagnetic obstacles, together with any bends or 'dog-legs' in the wire. As a result a very low SWR may not always be possible when the antenna is fed with 50 ohm coaxial cable.

Because the dipole is a balanced symmetrical antenna, ideally it should be fed with balanced two-wire feeder. However, because almost all transmitters use a 50 ohm coaxial line antenna socket, coaxial cable is almost universally used to feed the dipole antenna. Connecting unbalanced coaxial cable to a balanced antenna does not normally affect the performance of the antenna provided the unbalanced current on the coaxial line is kept to a minimum. This can be done by making sure the coaxial line is not a multiple of an electrical quarter wavelength (see Chapter 11) and that the coax line comes away from the antenna element at an angle as close to 90 degrees as possible.

Antenna currents on the line, which can cause the line to radiate (and cause TVI or BCI) should not be confused with SWR. A high SWR on transmission line does not cause it to radiate.

A current choke Balun can also be used to reduce these antenna currents, see Chapter 11.

The inverted V

So far we have only considered a horizontal dipole. This antenna requires two supports and this may be a problem at some locations. The solution may be to mount the antenna with the centre supported in a singe pole and to let the droop to some convenient fixing point. Such a configuration is often referred to an inverted V antenna.

Supporting a centre fed antenna in the centre has some mechanical advantage because the weight of the feeder can be supported more efficiently. The down side of the inverted V is that maximum gain decreases as the ends of the dipole are reduced in height compared with the centre section.

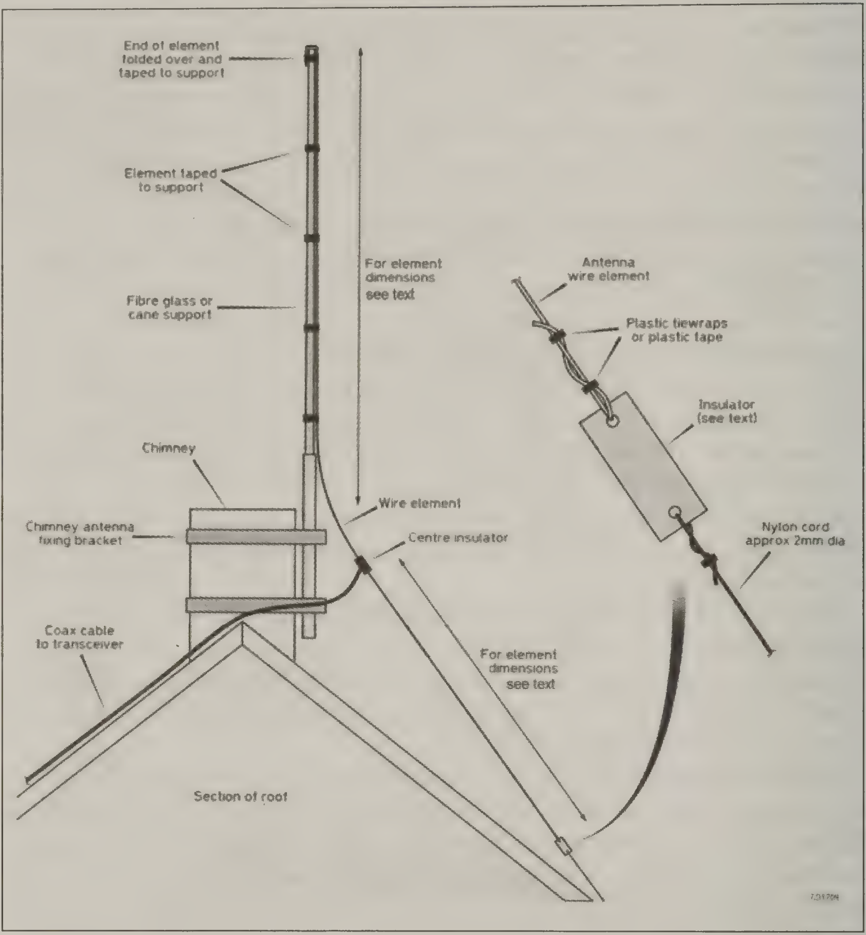

End of element folded over and taped to support
Element taped to support
Fibre glass or cane support
Chimney
Chimney antenna fixing bracket
Coax cable to transceiver
For element dimensions see text
Wire element
Centre insulator
For element dimensions see text
Section of roof
Antenna wire element
Plastic tiewraps or plastic tape
Insulator (see text)
Nylon cord approx 2mm dia

Fig 2.3: If horizontal space is restricted, the dipole can be orientated as a sloping or vertical antenna as shown. The dimensions are the same as for a horizontal dipole and they are given in Table A1 in Appendix 1. The element support can be weather-proofed cane or fibreglass. The elements can be made from plastic covered wire.

The vertical dipole

A vertical half wave antenna has some an interesting properties which you might find useful if you are interested in DX on the upper HF bands. The construction is shown in **Fig 2.3**. The comparative performance of a vertical dipole is shown later in this chapter.

On the lower HF bands a such an arrangement will probably result in a sloping dipole because of the length of the elements.

PARALLEL DIPOLES MULTIBAND ANTENNA

While the resonant dipole is a very efficient antenna that can be connected to the antenna socket of the transceiver without an ATU, it is a single band antenna. Using separate dipoles for each of the bands can result in a mass of wires. One solution is to use several dipoles fed in parallel from the same feed line. The length of each separate dipole is a half wavelength for each band so that each dipole presents a good impedance match to the feed line on the band for which it is intended and a poor match on all the others.

The multi-element structure is supported by the lowest frequency dipole as shown in **Fig 2.4**. Each dipole in the parallel-fed combination may be supported from different directions if different directions of radiation are desired and

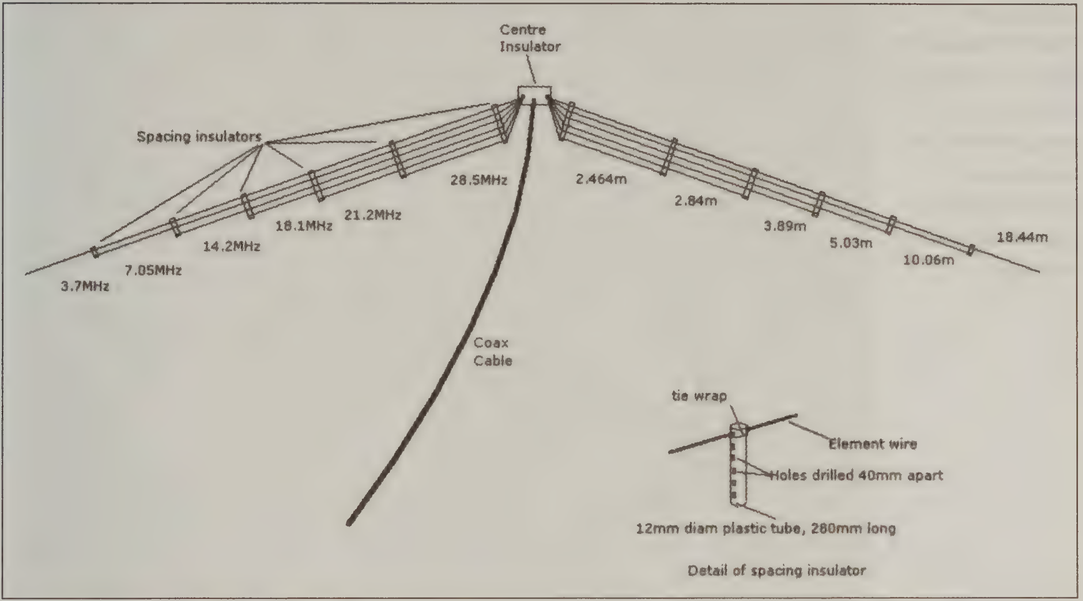


Fig 2.4: Dipoles can be connected in parallel using a common coax feeder. The detail shows the larger spacers to accommodate six wires. The outer spacers are progressively shorter with holes drilled for five, four, three and two wires respectively.

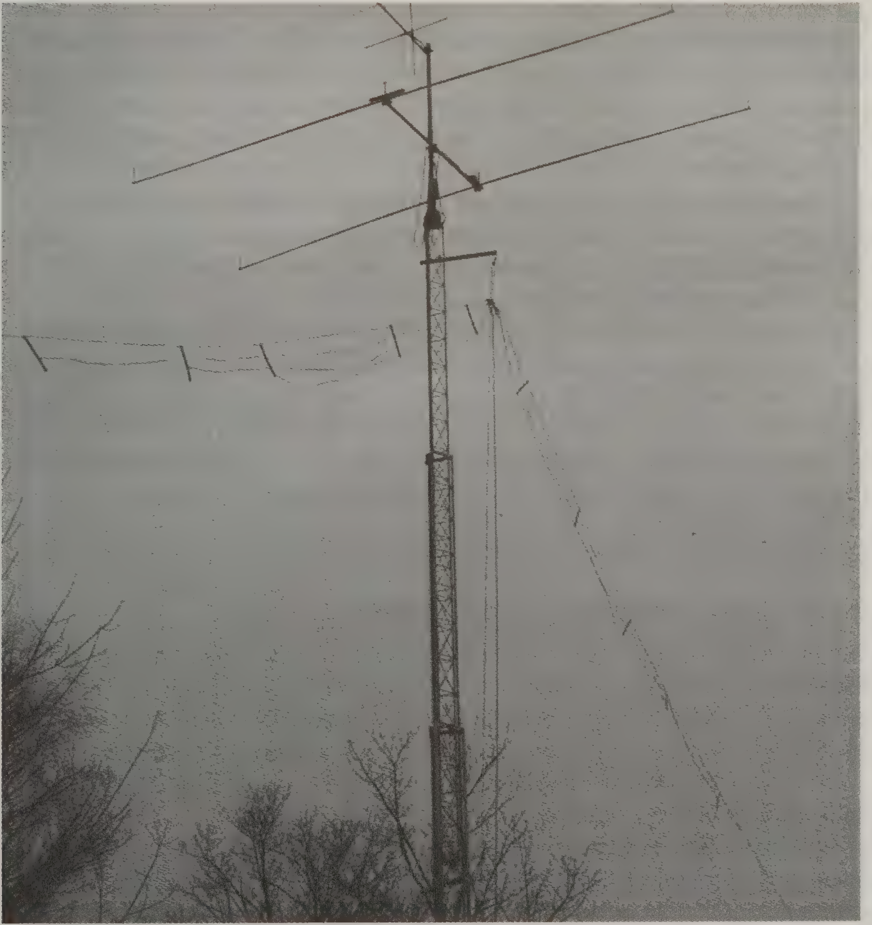


Fig 2.5: Multiband dipole arrangement, used at Amberley Radio Club, made from drop telephone wire and fed with coax.

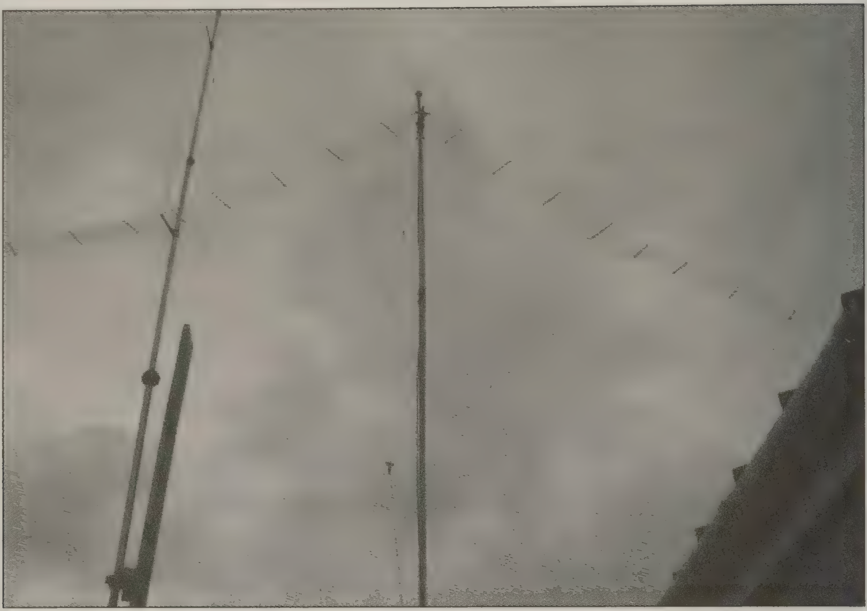


Fig 2.6: The GM4UTP multiband antenna showing the inverted V configuration. The antenna also supports a single quad element for 10 metres.

the space is available. This also has the advantage of placing the ends of the dipoles some distance apart. The ends of the lowest frequency dipole can be bent to fit into an available area if necessary but the length will have to be increased slightly from the normal dipole length to get the lowest SWR.

The multiband dipole proved to be successful at Amberley museum radio club, see **Fig 2.5**.

Stewart, GM4UTP, has a neat and interesting parallel dipole design. This arrangement uses the lowest frequency dipole to support the higher frequency dipoles using spacing insulators made from 11mm plastic electrical conduit. The construction is shown in **Fig 2.6**

The antenna is configured as an Inverted V with the weight of the centre insulator and the 1:1 balun mounted on a 10m high aluminium scaffold pole (Fig 2.6). Low centre band SWRs are possible if some time is spent tuning each dipole. This can be achieved by arranging the ends of the elements so that they are clear of their support insulators by about 200mm. The dipole lengths can be reduced or increased by folding back the end and securing with plastic tape.

The resonance of these dipoles can be interactive - when you adjust one it effects the resonance of the other so be prepared to have to re-resonate elements.

THE OFF-CENTRE-FED DIPOLE

We are mostly used to seeing antennas fed in the centre with a low impedance feeder. This is because the impedance of a half-wave antenna is about 50 ohms at the centre and about 4000 ohms at the ends. The impedance along the antenna can be accurately represented by a straight line on semi-log graph paper.

If this line is drawn for a half-wave 3.5-MHz antenna and additional plots for 7.0MHz and 14.0MHz are made for the same antenna, all three lines cross at two points at about the 280 ohm impedance mark. These two points are approximately 1/3 of the way from the ends of the antenna. The antenna can be fed with 300-ohm line at either of the triple-crossing points and it will work on all

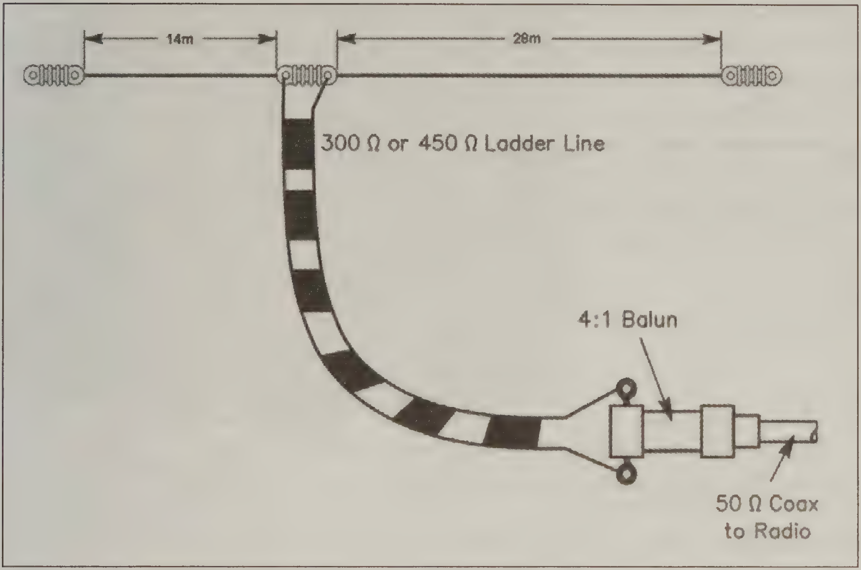


Fig 2.7: The basic Off-Centre Fed Dipole.

three frequencies. If the feeder is not connected at the exact crossing point it will still have an impedance of between 150 and 600 ohms. Such an arrangement is called an Off-Centre-Fed Dipole (OCFD) and is usable if your transceiver has an internal auto ATU, but would be unsuitable for the WARC bands without a wide impedance matching range ATU. It does result in some unbalance on the 300 ohm transmission line and a current choke or balun is required as shown in **Fig 2.7** to prevent antenna currents on the coax section of the feeder.

It is worth experimenting with this antenna. Altering the overall length is quite easy. Moving the feedpoint can be achieved by making one end longer and the other shorter. These variables can be made easier to adjust by making the top section longer than required and folding back the excess length at the end insulators back along the elements as shown in Fig 2.2(a). The excess lengths can be temporarily held in place with clothes pegs while measurements are made.

THE W6RCA MULTI-BAND DOUBLET

Many antenna designs feature combinations of doublet length and feedline length resulting in a convenient impedance (one easily matched by a transceiver's internal auto-ATU) at the bottom of the feedline for a few bands, but never all of them. Hence the need for an ATU with the open wire tuned multi-band dipole described above.

The following describes a more radical approach by Cecil Moore, W6RCA [1]. His solution to the problem covers all the HF bands from 3.6 to 29.7MHz with no ATU at all. This is achieved by changing the length of the 450 ohm line, and this is much more practical than it looks at first sight. The line length is adjusted for each band, so that the current maximum always coincides with the bottom of the feedline. The feed impedance at this point is then by definition low and non-reactive, and in practice the SWR is usually low enough that you can use a 1:1 choke balun, straight into coax and the transceiver. With reasonable lengths for the doublet and the permanent part of the feedline, you can always achieve an acceptable impedance match.

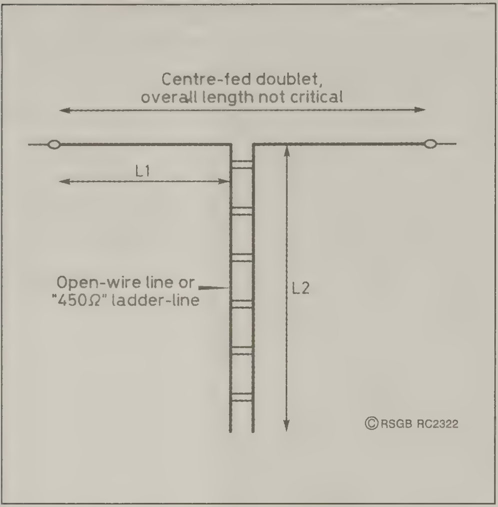


Fig 2.8: The HF multi-band doublet fed with ladder line can have a wide range of feed impedances. To estimate the impedance, measure half the length of the doublet (L1) plus the electrical length of the feedline (L2, allow for velocity factor).

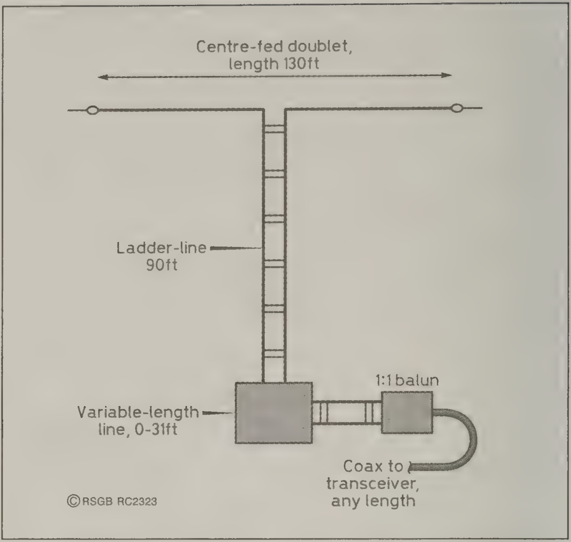


Fig 2.9: W6RCA's novel line-length switcher makes his 39.62m (130ft) doublet cover all eight HF bands with no ATU. Optimum dimensions will depend on local factors, but you can always change the line length to compensate

The requirement is that the physical half-length of the doublet (L1 in **Fig 2.8**), plus the total electrical length of the feedline (L2, allowing for the velocity factor v) must be an odd multiple of a quarter-wave-length on each band:

$$L1 + L2 \times v = n \times \lambda/4$$

where n is 3, 5, 7 etc

When you get out the calculator and start playing with figures, you can arrive at several possible solutions. The W6RCA arrangement is shown in **Fig 2.9**, with a 39.62m (130ft) centre-fed doublet and 27.5m (90ft) of 450-ohm ladder-line. The doublet is approximately a half-wave at 3.5MHz and a full-wave at 7MHz, and the 27.5m (90ft) feedline brings the current maximum to the bottom at 7.2MHz. The big practical advantage of this combination is that all the other bands can be matched within a relatively small range of additional feedline length. The longest additional length required is 9.5m (31ft) for 3.6MHz, which extends the feedline to an electrical half-wavelength.

All other bands require a line extension somewhere between zero and 9.5m, so W6RCA built a variable-length switcher shown in **Figs 2.10 and 2.11**. This consists of 300mm (1ft), 600mm (2ft), 1.22m (4ft), 2.44m (8ft) and 4.88m (16ft) loops of line, which can be individually switched in or out using DPDT relays, giving any length from zero to 9.5m in 300mm steps.

W6RCA found he could cover all amateur bands from 3.6 to 29.7MHz with a SWR of better than 2:1. The optimum dimensions will depend on a number of local factors. These include antenna height, earth properties, the use of other doublet configurations such as an inverted-V or inverted-U, and the exact type

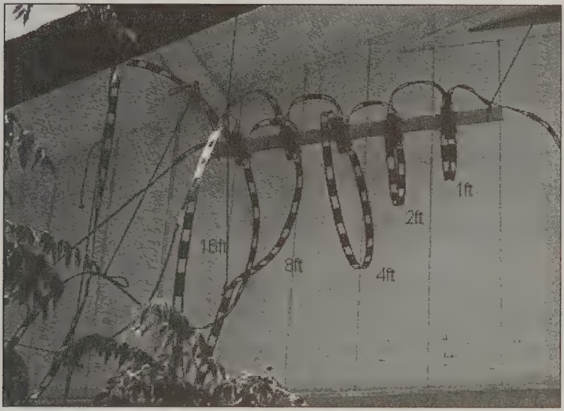


Fig 2.10: The practical line switcher. The horizontal rail holds the five pairs of DPDT relays. W6RCA points out that, with hindsight, it makes more sense to start with the 2.44m (8ft) and 4.88m (16ft) loops at opposite ends of the wooden rail that holds the relays. You could also change bands manually by using plug-in lengths of line for each band.

of feedline. So-called 'ohm' line varies considerably in characteristic impedance, velocity factor and quality (conductor diameter and insulation) between different brands; hence the need to experiment.

A battery-powered tuneable SWR analyser (see Chapter 12) is the perfect tool for the job of experimenting with line lengths and it should used via the 1:1 balun. You can easily make temporary splices in ladder-line using screw connectors - or just twisting the wires together. The first step would be to increase the permanent length of line by say a metre from the recommended length, then trim the feeder so that the SWR minimum occurs around 7.05MHz. You may find that the same length works well enough for 21MHz and 24.9MHz too. Next, determine the maximum extra length you will need to tune all the way down to 3.5MHz with an acceptable VSWR. This extra length should not be much more than 9.5m, and the optimum lengths for all the other bands will all be shorter than that.

Unfortunately the popular 32m (102ft) G5RV-style doublet is not very well suited to this arrangement, because it requires a much wider variation in the

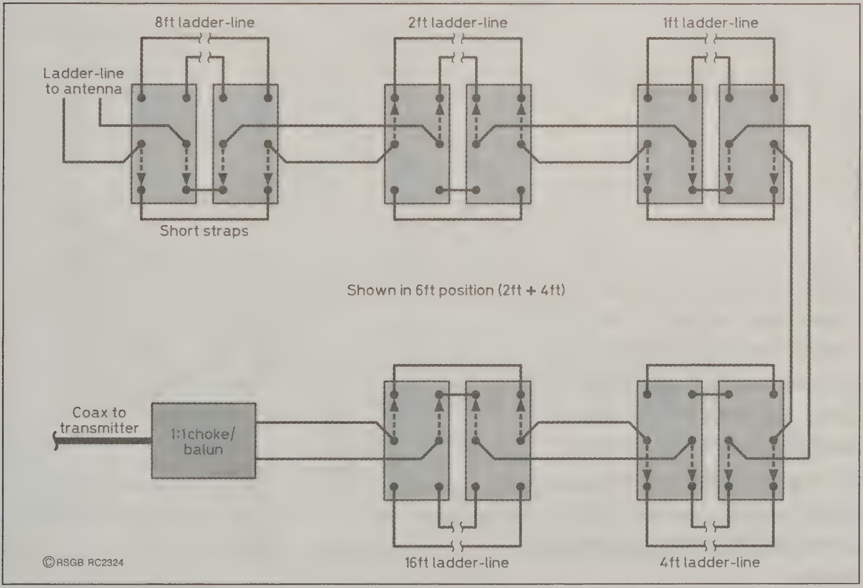


Fig 2.11: More details of W6RCA's line switcher, which uses five pairs of surplus DPDT relays. A suitable 1:1 choke balun is described in Chapter 11.

feedline length. If you're stuck with a 102ft 'flat-top', W6RCA recommends adding a 4.6m (15ft) vertical 'drop wire' at each end, and then you're back to the much more convenient situation of Fig 2.9. For a shorter doublet covering 7-29.7MHz, a 20.12m (66ft) doublet and a 18.3m (60ft) feedline as a good starting-point, again with a 0-9.5m variable section. Note also that the system can still be used as a shortened dipole on the next band below, but you will require an ATU and there may be significant losses in the ATU and feedline due to the very low impedance.

After the initial experiments, you can think about a more permanent arrangement. You don't have to build the complete line switcher. Practical solutions range from a fully manual system to a fully automatic system linked to the transceiver's 'band data' output (ideal for HF contesting in the single-antenna section). For occasional visits to certain bands, you could insert the necessary lengths of feedline using 4mm banana plugs and sockets (the silver-plated variety can be used permanently outdoors).

It wouldn't be difficult to string something along a wooden garden fence, so long as the loops of line are suspended clear from other lines, metallic objects or the ground.

The 1:1 balun is worth a brief mention. It's important to use a balun, because any low-impedance path to ground from either side of the feedline is likely to result in very strong unbalanced radiation from the feedline itself. This is a consequence of the 'odd quarter-wavelength' principle used in selecting the feedline length. A suitable choke balun is described in Chapter 11.

THE GROUND PLANE ANTENNA

The quarter-wave ground-plane antenna, is so named because of the radial ground wires. It is derived from a quarter wave antenna mounted on a metal sheet such as a VHF antenna on the surface of an aircraft. In the case of an HF antenna the metal sheet is replaced with four resonant radial wires as shown in **Fig 2.12**

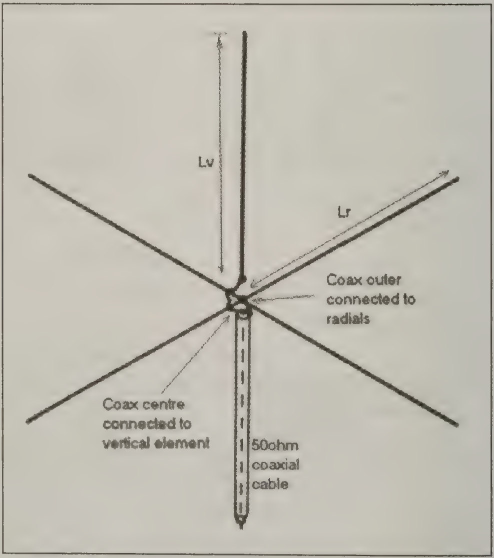

Lv
Lr
Coax outer connected to radials
Coax centre connected to vertical element
50ohm coaxial cable

Fig 2.12: The resonant radial ground plane antenna. The element lengths for a given frequency can be found from Table A1 of Appendix 1. The radial lengths are obtained by halving the figure in the (*) column and the vertical section by halving the figure from the (#) column.

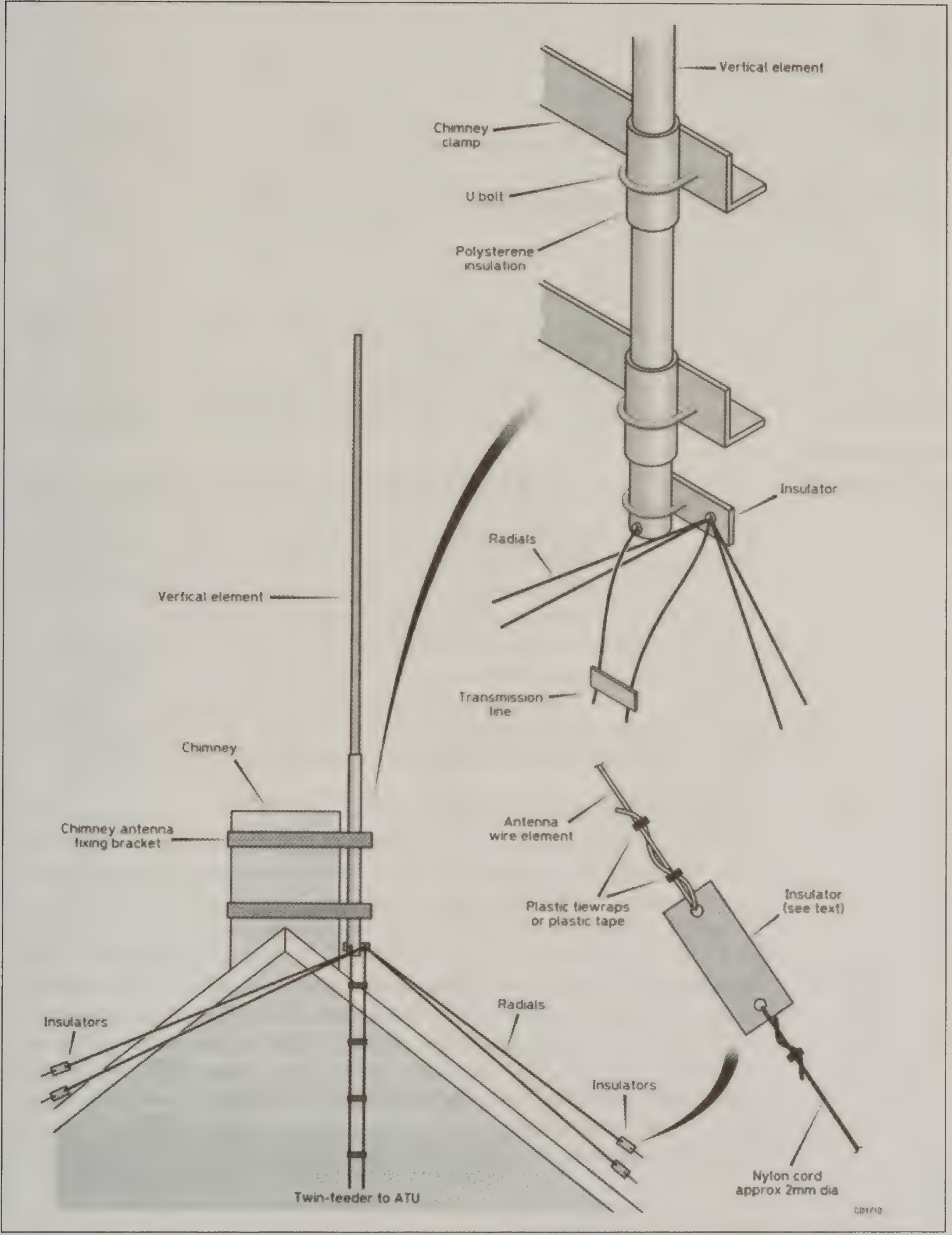


Fig 2.13: A practical construction arrangement for an elevated ground plane antenna using sloping resonant radials. The antenna is shown fed with twin wire feeder as a multiband antenna, which would require an ATU. For a single band antenna, feed with coax as shown in Fig 2.12. The dimensions are the same as for Fig 2.12.

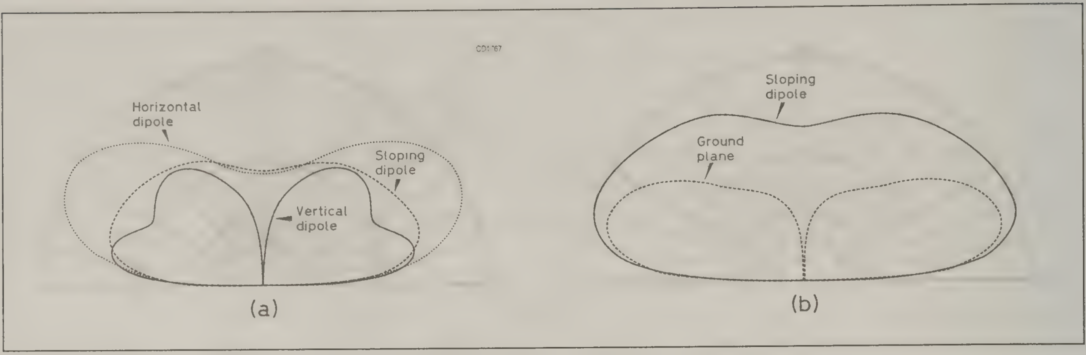


Fig 2.14: Elevation polar diagrams of vertical antennas compared with a horizontal dipole half a wavelength high.

The ground plane may be mounted with the radial wires a close to the ground, or elevated on the roof of a building.

The feed impedance of the ground plane is of the order of 30 to 35ohms, and it may be fed with a 50-ohm coaxial line with only a slight impedance mismatch.

Such an arrangement of horizontal radials is rather impractical with an elevated ground plane. A more practical arrangement is shown in **Fig 2.13**, where a metal vertical whip is used with the radials also acting as guy wires. The whip may be mounted on a post or tower, or on the roof of a building.

A further advantage of using sloping radials is that the feedpoint impedance is raised to about 50ohms, giving a better match to 50-ohm coax.

The vertically orientated antenna is often cited as having a good low angle of radiation. From the graphic data obtained from EZNEC shown in **Fig 2.14** this appears to be true. The elevation plot shows a ground plane whose feedpoint is only 0.2 wavelengths above the ground, which equates to 3m (9ft) on 21MHz. It has a very deep vertical null but the maximum gain is only 0.45dBi.

THE G5RV ANTENNA

The G5RV is often cited as a simple multiband antenna that does not require an ATU. This is not the case. When G5RV devised his antenna it was meant to be a good performer on 20m and adequate for inter-G contacts on 80m. At that time we had no WARC bands, no 15m band and 10m was still dead. 20m was the main DX band and 80m the 'ragchewers' band. Few people could afford a beam (homebrew of course!). Coax was not in common use but 80-ohm balanced twin or even twin lighting flex was. This gave a low SWR with the feed impedance of 90-100 ohms for three half waves on 20m, whilst the mismatch on 80m was acceptable with the Pi network output circuits used on transmitters at the time. Later G5RV emphasised that on other bands a full-length open wire feeder should be used with a balanced ATU. Then it was no longer a 'G5RV' but a tuned line doublet antenna, which is described in Chapter 3.

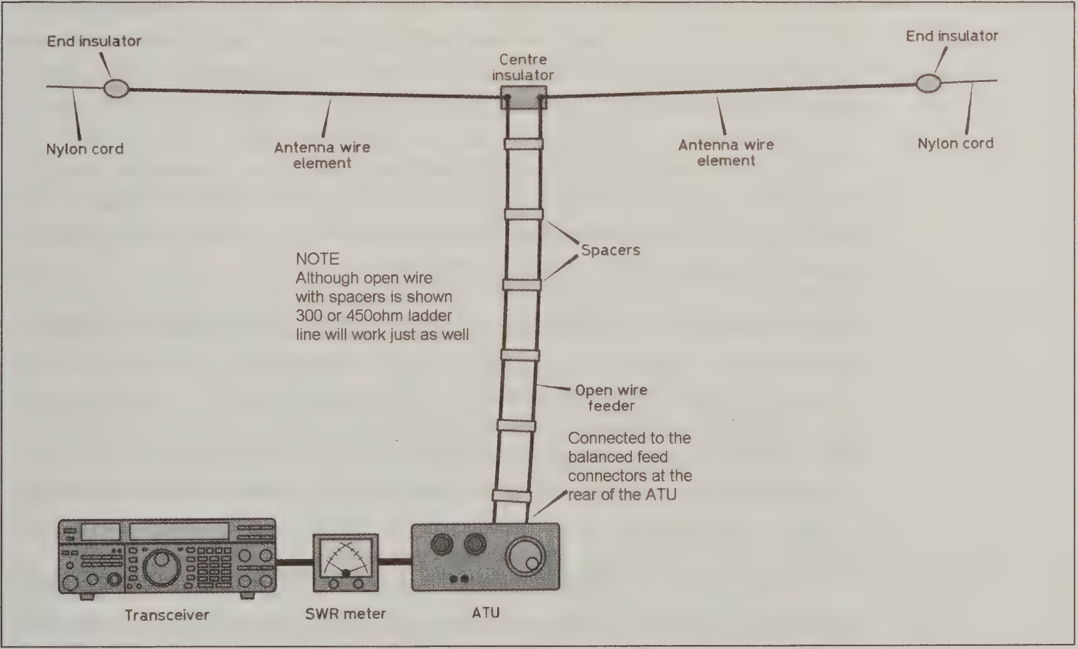
3

Simple multiband HF antennas

This chapter deals with simple multiband antennas that require an Antenna Tuning Unit (ATU) to function efficiently. Descriptions of ATUs can be found in Chapter 4. This chapter also describes RF earth or ground systems because they are so important to the performance of end fed long wire and Marconi type antennas.

THE TWIN FEEDER TUNED DIPOLE

If you feed a length of wire in the centre you do not require a counterpoise or RF ground system. You can use a resonant dipole fed with coax but this is a single band arrangement. A better solution is to use what is known as the Tuned Doublet or Random-Length Dipole shown in **Fig 3.1**. It is very simple, yet it is a most effective and efficient antenna for multiband use.



NOTE
Although open wire
with spacers is shown
300 or 450ohm ladder
line will work just as well

Connected to the
balanced feed
connectors at the
rear of the ATU

Fig 3.1: The tuned open-wire dipole using a tuned transmission line. If you are short of space the antenna could be cut for 3/8 of a wavelength on 7MHz and it will tune all bands from 7 to 28MHz. The real advantage of this antenna is that dipole length is not critical, because the tuner provides the impedance match for the entire antenna system, whatever the dipole length and feeder might be.

The antenna is fed with open wire tuned feeders. This type of feeder or transmission line has the advantage of low loss, even with a high SWR and long runs. You can use open wire feeder or any commercial 300 or 450-ohm ladder-line. An ATU with a balanced feed is used to take care of the wide variations of feed impedance on the different bands.

If you haven't already got an ATU I strongly advise you get one. Unlike your latest radio an ATU is a low tech bit of kit and will last a lifetime. The traditional T match with a balun at the output for balanced feeders is the most popular and is fine. They come in different prices depending on power handling requirements and whether or not it has a built in SWR meter (a useful feature). ATUs are discussed in Chapter 4.

Most information available indicates that the Tuned Doublet should be at least half a wavelength long at the lowest frequency of use.

However I have found that the doublet can be reduced to 3/8 wavelength on the lowest frequency, which still has an effectiveness greater than 98% relative to a half wave dipole and impedance values which are reasonably easy to match. A 3/8 wavelength dipole at 3.5MHz is approximately 30m (100ft) long, which will make an excellent radiator on all HF amateur bands, 80 to 10 metres, including the WARC bands. This can cause loading difficulties which can be overcome by selecting a different ratio on the balun (see below) or altering the length of the twin feeder.

If you don't have room for a 30m length of straight wire for operation on 80 metres, a 3 to 5m (10 to 16ft) portion of each end may be dropped vertically from each end support. There will be no significant change in radiation pattern on 80 and 40 metres. However, there will be a minor change in polarisation in the radiation at higher frequencies, but the effect on propagation will be negligible. This antenna can also be supported using a single pole to form an inverted V although the ends should be fixed as high as possible.

If you are willing to forgo the 3.5MHz (80m) band then a centre fed wire half the length quoted above will work on all bands from 7 to 29MHz including the WARC bands. And remember, the dimensions of this antenna are not critical, unlike the resonant dipole or the G5RV.

PORTABLE ANTENNA USING TELESCOPIC POLE

The Open Wire Tuned Dipole makes a very good antenna for portable use. A telescopic fibre-glass pole can be used as the centre support. For transportation these poles can be telescoped down to about 1.2m and some can be extended to 10m. An ATU is required with this antenna arrangement, however with the size of rigs such as the IC-706, a good quality ATU such as the MFJ-901B (see Chapter 4) and a small switch-mode power supply means that you can have portable station with a base station performance.

A lightweight antenna like this can be placed on the balcony or roof of a hotel or apartment because of its very low visual impact. When the support pole is expanded the feeder and the centre insulator made from a screw connector block can be fixed to it using plastic insulated tape. The insulators can be made from clothes pegs or spring clips as shown in **Fig 3.2**.

The length is not at all critical (a major advantage when planning an antenna for a location that you have never seen) and a 20m centre fed length has worked

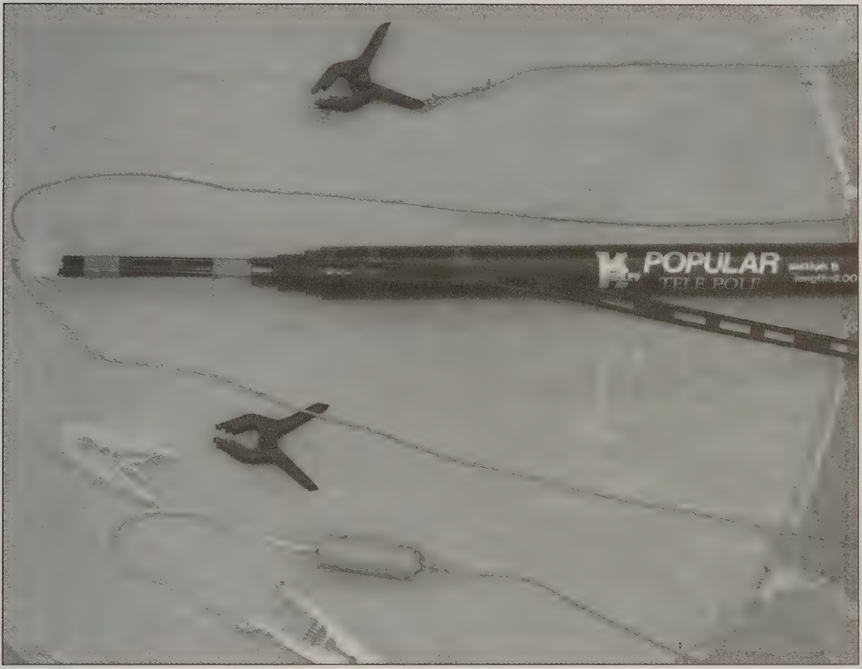


Fig 3.2: Components for a lightweight portable open wire tuned dipole . The centre support is a telescopic fibreglass pole. The insulator (made from a screw connector block) and the 300-ohm feeder is fixed to the centre support with insulated tape. The insulators can be made from clothes pegs or spring clips, which are also useful for fixing the element ends to any convenient supports

well for me. The antenna needs to be supported above the hotel or apartment roof, preferably at the centre where the radiation is the greatest.

The lightest and most portable of masts available is a telescopic fibreglass pole, which was originally made for fishermen and is called a roach pole. This pole is only 1.2m long when telescoped and will open to a 12m long tapered pole when fully extended. Furthermore, this item can be carried in hand luggage as a walking stick on the vacation flight.

The antenna can be installed by attaching the centre to the top of the support pole, which can then be fed with 300-ohm ladder-line feeder taped to the pole. This makes for an efficient antenna that is both lightweight and inconspicuous. 300-ohm ladder-line is very convenient for running through gaps in doors or windows. The support pole can then be fixed to most convenient upright building structure using tape, tie wraps or string.

An essential item, when using such an antenna, is a suitable ATU with provision for feeding a balanced antenna. I tried to make a small ATU that would handle 100W but found the right sized components rather expensive and difficult to find. Instead, I found a suitable small moderately priced unit, the MFJ-901B, see Chapter 4, which is not much larger than a FT-817 transceiver and weighs only 600gm.

PA0SE'S COMUDIPOLE ANTENNA

While the open-wire tuned dipole is a very good antenna there are problems, in many locations, of bringing open wire feeder into the shack. This is because twin feeder must not be allowed to come close to metal objects such as metal window frames, guttering or flashing and particularly electrical wiring. Metal objects close to the line can cause the currents in the line to be unbalanced. On the other hand coax cable is fully screened and can be allowed close to metal

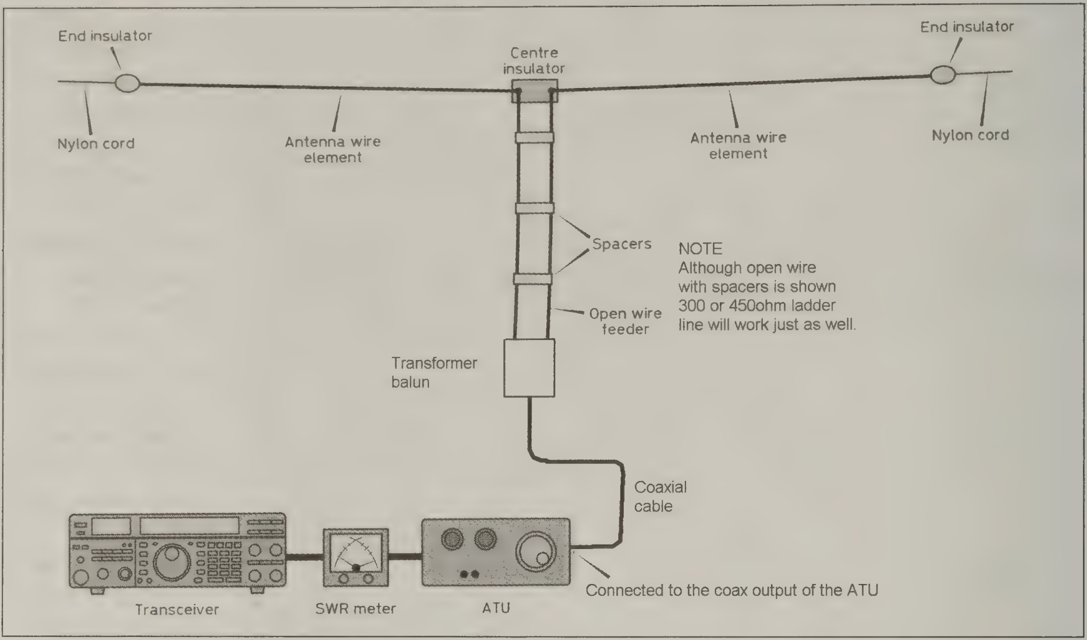


Fig 3.3:PA0SE's Comudipole antenna . The balun can be positioned any where along the line but the coax section should be kept as short as possible.

objects but has greater losses. The solution, if you do not have a clear run from the antenna to the ATU, is to use part coax and part balanced feeder, a solution first described by PA0SE (see **Fig 3.3**).

All this arrangement does is to move the balun, normally located inside the ATU, to a place outside the ATU and the shack making a more convenient connecting point for open line feeder. It is connected to the coax output socket of the ATU. Although the position of the balun is not critical the coax section should be kept as short as possible to keep the losses down. You don't have to physically remove the balun from your ATU! You can buy one, or make one as described below.

Many published and commercial T match ATU designs use a 4:1 transformer balun to provide a balanced input for impedances in the range 150 - 600 ohms.. However, under certain circumstances a low impedance is presented to the balun on some bands depending on the length of the antenna and the length of the feeder. It is very easy to design the balun to include 1:1 ratio which can be selected from 4:1 by a selector switch or coax connector. This will expand the range of balanced inputs from about 45 to 600 ohms without introducing any noticeable losses into the system.

The balun transformer is wound on a single Amidon T200-2 powdered-iron core, colour coded red. For sustained high-power operation, 400W plus, two such cores can be taped together by using plumbers' PTFE tape, which can also be used to provide an added layer of insulation between the core and the windings. A source of T200-2 cores can be found in Appendix 1. The design of the balun and the construction description below is by G3TSO.

Balun construction is simple, but a little cumbersome; some 14 turns of l6SWG enamelled-copper wire have to be wound trifilar fashion onto the toroidal core. That is to say, three identical windings are wound on together. Care must be taken to ensure that the windings do not overlap or cross one

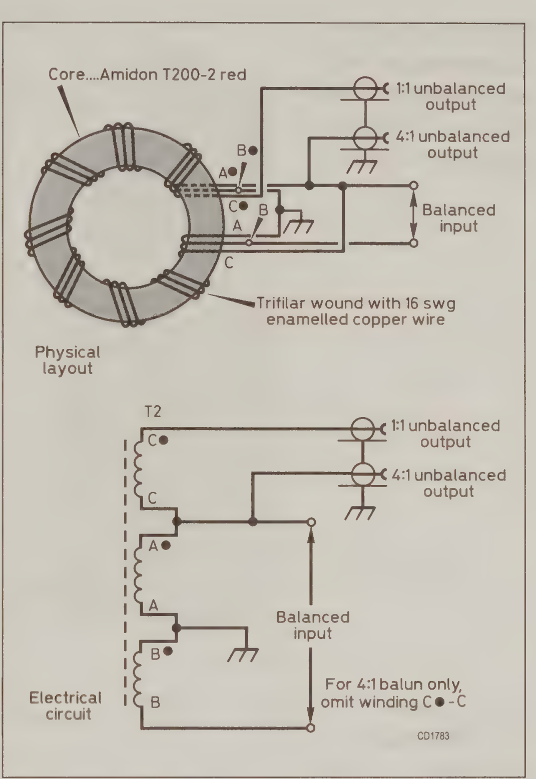


Fig 3.4: A 1:1 and 4:1 transformer balun wound on a T200-2 core.

another and that neither the core nor enamel covering is badly scratched during construction.

Fourteen turns will require approximately 97cm (38in) of 16 SWG (1.6mm) wire, so cut three equal lengths of 16SWG wire slightly longer than required and pass all three wires through the core until they have reached about halfway. This now becomes the centre of the winding and it is easier to wind from the centre to either end rather than from one end to the other which involves passing long lengths of wire through the toroid. The T200 size core will accommodate 14 turns trifilar without any overlapping of the start and finish of the winding. Close spacing will occur at the inside of the core, and a regular spacing interval should be set up on the outside. A small gap should be left where the two ends of the winding come close together.

Connection of the balun requires care and it is necessary to identify opposite ends of the same windings, which can be done with a continuity meter, with some form of tagging or colour coding being worthwhile. On the circuit diagram a dot is used to signify the same end for separate windings. It is essential that the various windings are correctly connected if the balun is to work properly.

Details of how the balun transformer is wound and connected are shown in **Fig 3.4**. Construction of a 4:1 balun only is slightly simpler and only requires two (bifilar) windings.

THE END-FED MULTIBAND ANTENNA

The end-fed antenna is simple, cheap, and easy to erect; suits many house and garden layouts and is equally amenable to base or portable operation. An example of an end-fed antenna, which is connected directly to the ATU is shown in **Fig 3.5**.

An antenna directly connected to the transmitter is often discouraged because of the close proximity of the radiating element to house wiring and domestic equipment. This undesirable feature is aggravated by the fact that wild excursions of feed impedance occur when changing operation from band to band and good matching can sometimes be difficult to achieve.

An end-fed antenna is often used without an efficient earth connection, but this can make it inefficient. Why is this? Let us consider the simple half-wave dipole. Looking at it from the point at which it is fed; the centre of the coax is connected to one wire and the braiding to the other as shown in **Fig 3.6**. Each wire is a quarter wavelength long and both wires radiate equally. The arrangement is good for one band only, although additional wires could be added to make a multiband dipole as shown in Chapter 2.

Fig 3.5: The end-fed antenna, the simplest of all multi-band antennas.

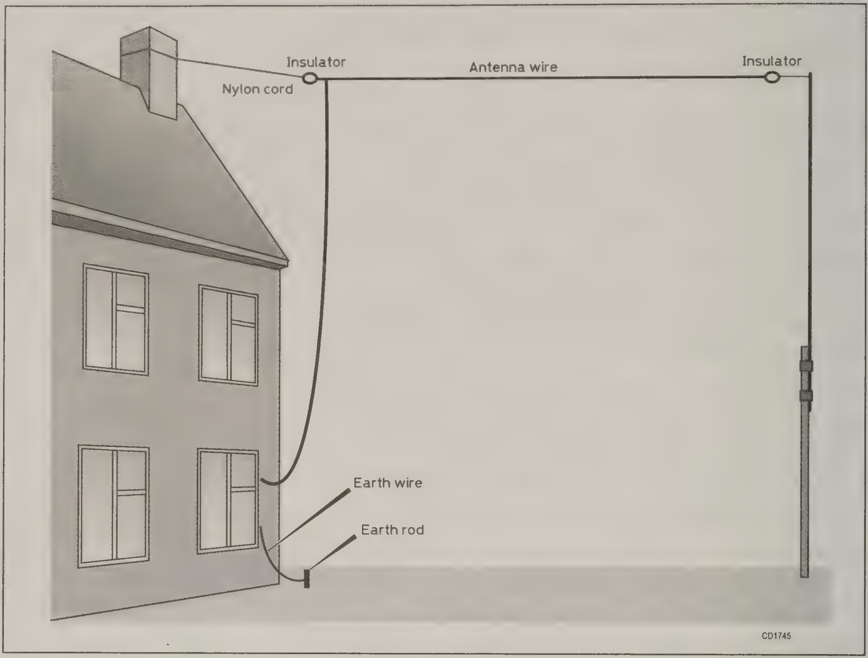
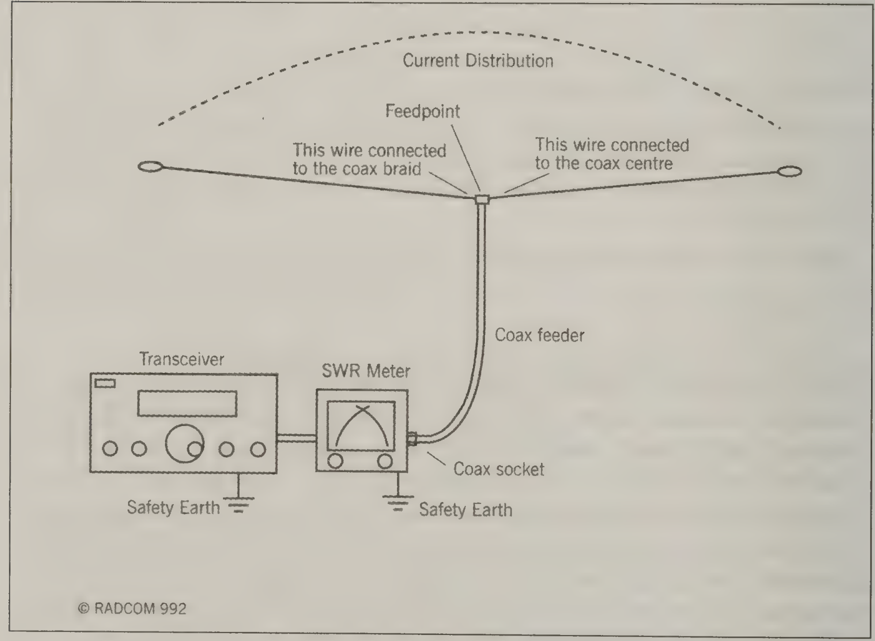


Fig 3.6: Simple dipole showing the RF current distribution. The earth is provided for electrical safety rather than a RF ground.



Now supposing the dipole is now orientated so that it is vertical with the left-hand wire uppermost. This wire, which is connected to the centre of the coax could now be considered as the 'antenna' and the other wire, connected to the coax braiding, as the 'counterpoise'.

The current in both wires is still equal provided they are both quarter of a wavelength long. Note that the transceiver is earthed. This is included for electrical safety reasons and may not be a good RF earth.

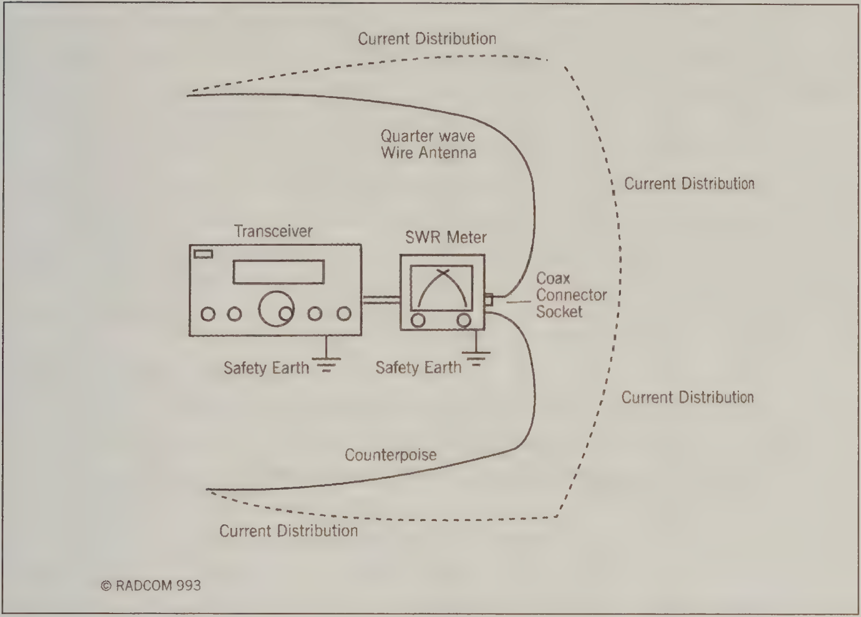


Fig 3.7: A resonant quarter wave end fed wire and resonant counterpoise

The resonant counterpoise

Suppose we now dispense with the coax feeder and connect the 'antenna' wire to the centre pin of the antenna socket of the transceiver in the shack (via the SWR meter), as shown in **Fig 3.7**. Where is the 'counterpoise' to be connected now? In the case of the dipole it is connected to the braid of the coax as shown in Fig 3.6. The only place it can be connected to now the outside part of the coax socket. A more practical connection point would be the ground connector of the transceiver, which will be at the same RF potential as the outside of the coax socket.

This arrangement will work only provided that the 'antenna' and the 'counterpoise' are quarter wave (or multiple) resonant at the frequency in use as with the case of the dipole described above. Any conductor carrying a RF current will radiate. A counterpoise is part of the antenna transmitting and receiving antenna and radiates on transmit so some consideration should be given to where it is placed. Just putting the counterpoise under the shack carpet may not be the best place for it.

The multiband end-fed antenna

It was noted earlier that the end-fed antenna must be resonant at a quarter wave (or multiple) to present a low impedance to the transceiver antenna socket. Traditional multiband end-fed antenna designs use a quarter wave wire resonant on a lower band in the HF spectrum, say quarter wavelength on 80m where the feedpoint will be around 50 ohms. At a half wavelength on 40m, the input impedance will rise to a high value presenting a voltage feed to the source. The next band, 30m, will fall in the vicinity of current feed again at three-quarter wavelength and present a fairly low impedance. The next move to 20m will encounter a high impedance again and then through an off tune 17m to another high at 15m. The sequence continues with extra complications in that odd multiples of one wavelength will show generally increasing impedance with frequency whereas

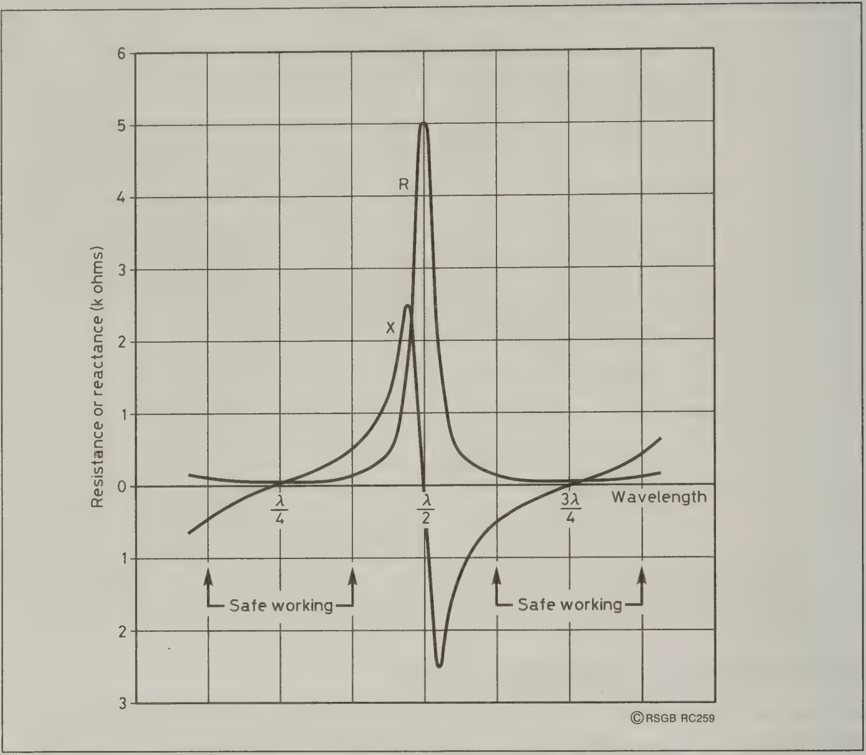


Fig 3.8: End fed Impedance characteristics of a wire from one quarter wavelength to three quarter wavelengths. Values of impedance that are more easily matched using an ATU if the wire lengths are within the designated 'safe working' area'.

even multiples of wavelength (the halfwave points) will show decreasing impedance as the band is ascended.

The resistance and reactance of a wire antenna, plotted against electrical length from below λ/4 to 3λ/4 and beyond, is illustrated in **Fig 3.8**. It can be seen that dramatic changes begin to occur as the λ/2 (half-wave) resonant point is approached. These changes are repeated at multiples of λ/2.

In spite of these wide variations of antenna feed impedance on different bands the transceiver can be matched to the antenna using a suitable ATU.

If the feed impedance differences that occur from one band to another can be moderated then a simpler ATU can be used. This is achieved by using antenna wire lengths, which steer clear of the half-wave points. This would allow the end-fed antenna to be matched on all bands by any of the ATUs described in Chapter 4. The selection of an optimum antenna length was described in detail by Alan Chester, G3CCB [1], although this was done originally to meet the limitations of a wideband matching transformer system.

In **Fig 3.9**, wire length is shown against each of the nine HF bands, including 160m. The

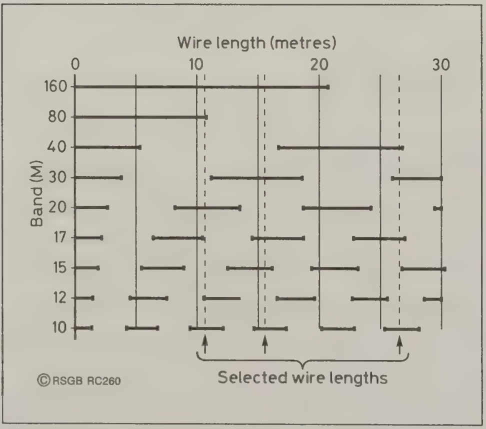


Fig 3.9: Antenna wire lengths, showing high impedance lengths for various bands.

heavy lines indicate areas where impedance excursions might fall outside the matching capabilities of many ATUs. These lengths were calculated by G3CCB from the lower band edge frequency in each case and no corrections were made for the 'end effect' on a real antenna.

To use the chart shown in Fig 3.9, a perpendicular straight edge is dropped from the horizontal axis and moved along until a clearest way through the gaps between the extreme impedance sectors is found. There is a minimum antenna length shown which depends on the band in use. This restriction, which may be of interest to those operating from a restricted size site, can be overcome by using a loading coil - this is described later.

Earth lead tuner

Earlier I said that the counterpoise also has to be resonant. The favoured method of obtaining a good RF earth is to connect a quarter-wave radial for each band to the transceiver and ATU earth connector, with the free ends outside the shack running the, away from the transceiver.

Because the current at the end of the wire is zero and the impedance is high it follows that at a quarter wave inward, where it connects to the transceiver, the RF voltage potential is low (the impedance is low). The problem is where to locate all these radials and such an arrangement will require some experimenting to find the best position for them. Radials can be bent or even folded but the length may have to be altered to maintain resonance. The radials are best located outside the house in the horizontal plane to reduce coupling into the electrical wiring. If the radial(s) are used indoors (ie round the skirting board) use wire with thick insulation with additional several layers of insulating tape at the ends where the RF voltage can be fairly high when the transmitter is on.

The best way to check resonance of a radial is to connect it to the radio earth, make loop in the radial and use a dip meter to check resonance. If such an instrument is unavailable then use an RF current meter (see Chapter 12) and adjust the radial length for maximum current.

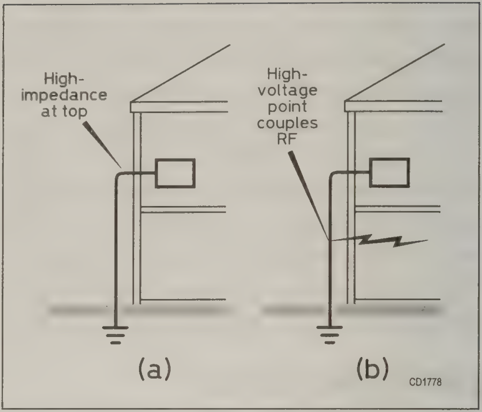
But just like the antenna itself, one single length radial can be tuned to place a very low RF potential at the transceiver on any band by inserting a LC series tuning circuit between the transmitter and the radial. Such a units are commercially available and the MFJ 931 [2] is an example of one of these, and is described as an Artificial Ground. This unit and a home brew counterpoise tuner are described in Chapter 4.

Using real earth

So far we have only talked about a resonant counterpoise to present a low impedance at the antenna socket of the transceiver or ATU. However if the counterpoise has what you might describe as a large electrical 'mass' this will present required low impedance over a range of frequencies. You only have to think of a mobile installation where the vehicle itself is the counterpoise system.

You can use earth or ground itself as a counterpoise by just driving a copper pipe into the ground and connecting it to the earth connection on the radio or the ATU. The problem is that the RF resistance of the earth is a very variable factor. Many ways have been tried to reduce the ground resistance. In general, the more copper you can bury in the ground the better. An old copper water tank,

Fig 3.10: Why RF ground leads from upstairs seldom work.
(a) Ground lead with quarter-wave resonance (or odd multiple) is ineffective; very little current will flow into it.
(b) Ground lead with half-wave resonance (or multiples) will have high-voltage points, which couple RF into house wiring.



connected to the radio with thick short copper wire, makes a very good earth for the lower HF bands.

In practice a good RF earth connection like this is only practicable from a ground floor shack or at the base of an antenna. The problem with the 'earth stake' is that ground has resistance and the lead connecting the earth stake radio has reactance.

The distance from the earth connection to an upstairs shack is a significant fraction of a wavelength on the higher HF bands and above. G3SEK [3] makes the point that at frequencies where this length is near one or three quarter wavelengths, the earth connector will act as a RF insulator, which is just the opposite of what is wanted, see **Fig 3.10 (a)**. This is bound to happen in one or more of our nine HF bands.

On the other hand, if the lead resonates as a half-wave, (a situation that is likely to arise on any band above 10MHz), it may act as a good RF earth. However, it also has a high-voltage point halfway down which may couple RF into the house wiring, see **Fig 3.10(b)**, because electrical wiring within the wall of a house is generally perpendicular. In other words although an earth wire from the radio in an upstairs shack to an earth stake will provide a safety earth its usefulness as an RF earth is unpredictable.

There is a further consideration to having a good earth other than antenna efficiency. A poor or non-existent RF earth can result in the casing of the radio equipment being at a high RF potential. Furthermore, the microphone, key or headset leads are also 'hot' with RF so you get RF feedback and BCI problems. Additionally, the IC circuits of modern communications equipment (keying or microphone circuits) are easily damaged in these circumstances by high RF voltages.

The remotely tuned end-fed antenna

Placing the antenna feedpoint at a remote point from the shack, as shown in **Fig 3.11**, can circumvent the disadvantages of bringing the end of an antenna into the shack, described at the beginning of this chapter and discussed in Chapter 1. Locating the long-wire antenna feedpoint away from the house minimises electrical noise on receive and EMC problems on transmit. Furthermore, it reduces the unpredictable effect on the antenna caused by possible conduit, wiring and pipe resonances.

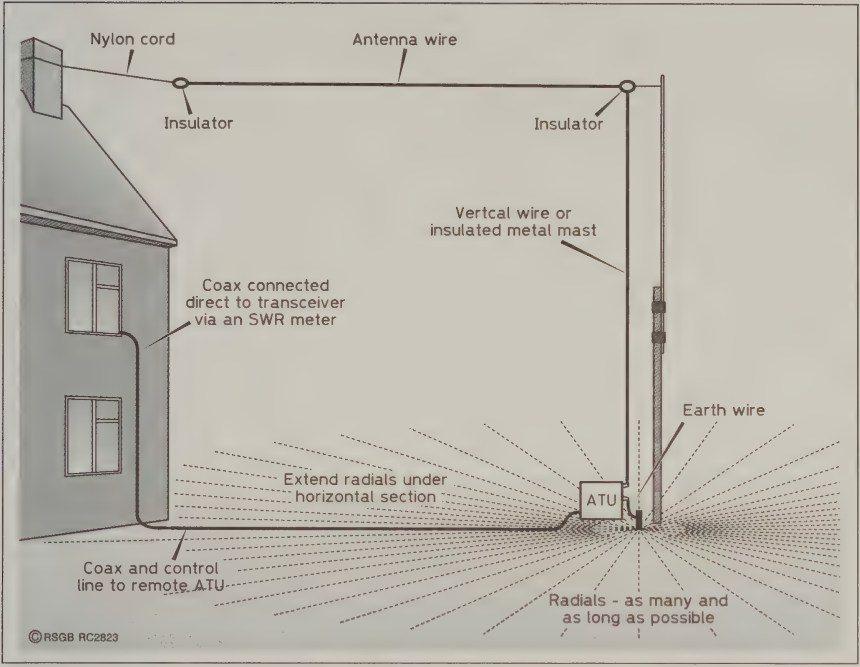

Nylon cord
Antenna wire
Insulator
Insulator
Vertcal wire or insulated metal mast
Coax connected direct to transceiver via an SWR meter
Earth wire
Extend radials under horizontal section
ATU
Coax and control line to remote ATU
Radials - as many and as long as possible
©RSGB RC2823

Fig 3.11: A remotely fed long wire antenna arrangement with multiple radials. The ATU may require a control cable in addition to the coaxial cable feeder.

In addition such an arrangement makes it easier to install radials, which are discussed later.

The disadvantage of this arrangement is that the ATU is some distance from the transceiver, which can be rather inconvenient when it comes to making adjustments when using a manually tuned ATU. Some sort of remote control of the ATU is necessary but there are now many commercial automatic ATUs on the market.

Buried radials

There is another way of improving the ground effectiveness and that is to use buried multiple radials; lots of wires radiating out from the earth connection. Because these radials are buried they are not resonant but work very well as an RF earth. On the face of it the rule seems to be is the more wires the better. But is there an optimum size and number for radials?

John Stanley, K4ERO [4], presented the data in a sort of 'cost-benefit' style shown in **Table 3.1** and created a new figure of merit; the total amount of wire needed for various radial configurations. This is expressed in terms of wavelengths of total radial wire.

Examples:

- If you can only install 16 radials (Case A), they needn't be very long - 0.1 wavelength is sufficient. You'll use 1.6 wavelengths of radial wire in total, which is about 137m (450ft) at 3.5MHz.
- If you have the luxury of laying down 120 radials (Case F), they should be 0.4 wavelengths long, and you'll gain about 3dB over the 16-radial case. You'll also use a total of 48 wavelengths of wire. For 3.5MHz that would be about 4115m (13,500ft)!

Table 3.1: The loss in transmitted signal compared to the cost (and effort) needed to install more radial wires.

Optimum Ground-System Configurations

Configuration Designation	A	B	C	D	E	F
Number of radials	16	24	36	60	90	120
Length of each radial in wavelengths	0.1	0.125	0.15	0.2	0.25	0.4
Spacing of radials in degrees	22.5	15	10	6	4	3
Total length of radial wire installed, in wavelengths	1.6	3	5.4	12	22.5	48
Power loss in dB at low angles with a quarter-wave radiating element	3	2	1.5	1	0.5	0*
Feed-point impedance in ohms with a quarter-wave radiating element	52	46	43	40	37	35

Note: Configuration designations are indicated only for text reference.

**The loss of this configuration is negligible compared to a perfectly conducting ground*

- If you can't put out 120 radials, but can install 36 radials that are 0.2 wavelengths long (Case C), you'll lose only 1.5 dB compared to the optimal Case F. You'll also use 5.4 wavelengths total of wire, or 457m (1,500ft) at 3.5MHz.

Table 3.1 represents the case for 'Average' quality soil, and it is valid for radial wires either laid on the ground or buried several inches in the ground. Note that such ground-mounted radials are detuned because of their proximity to that ground and hence don't have to be the classical quarter-wave length that they need to be were they clear of the ground.

In his article K4ERO also made the point that ground-radial losses would only be significant on transmit, since the atmospheric noise on the amateur bands below 30MHz is attenuated by ground losses, just like actual signals would be. This limits the ultimate signal-to-noise ratio in receiving.

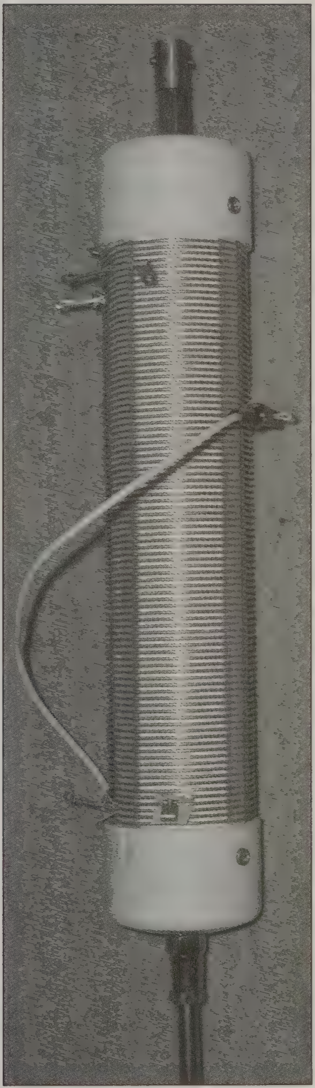
ELECTRICALLY SHORT ANTENNAS

If you are very short of space then an electrically short antenna, with a loading coil to bring it in to resonance, may be the solution. They can be reasonably effective - mobilers use them all the time.

The simplest solution is just to use a mobile antenna. The Texas Bugcatcher, which is become very popular in the USA, is described here as a solution for multiband operation on HF from a very restricted site.

This commercial mobile antenna uses the older traditional centre loading with a low loss coil or resonator. The lower section of the antenna below the coil is 600mm (24in) long, with an optional 400mm (16in) extension rod. The antenna screws into standard 3/8 x 24in threaded antenna mount.

The coil (resonator) is 300mm (12in) long and 63mm (2.5in) outside diameter. The coil has 90 turns wound over 254mm of the former and the bands are selected using a shorting lead with a crocodile clip to connect to preselected coil clips.



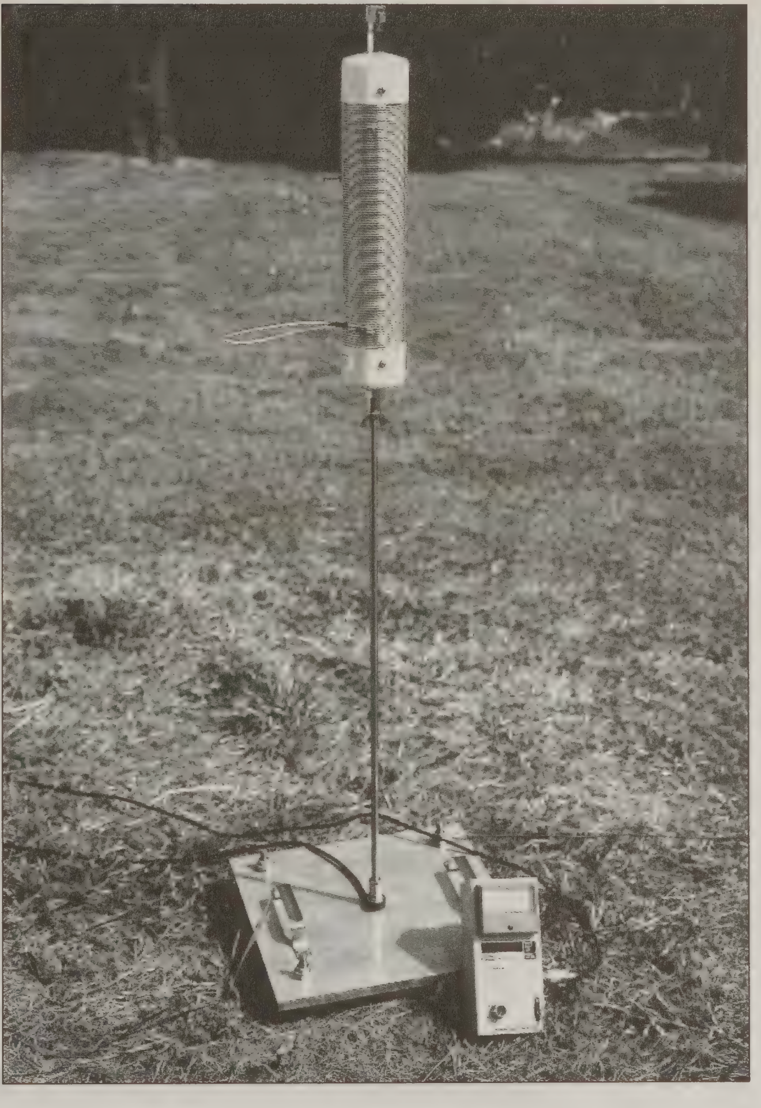


Fig 3.12: The loading coil with most of the coil clips fitted. Small insulating tabs have been fixed to some of the coil clips to prevent shorting to adjacent windings.

Fig 3.13: An earth plate, available from the manufacturers of the Bugcatcher, can be fixed in the lawn to make a fixed grounded vertical. The top of the coil is not very high in such an installation and there will be a high RF voltage there if you are using a lot of power. It is important that the arrangements are made so that no-one can come into contact with the coil or the top of the antenna when you are operating. [Photo courtesy of Waters & Stanton]

The top whip section is 2.2m (48in) long with a capacity hat in the centre to reduce the length of the antenna. If the capacity hat is not desired for any reason, it may be removed and a 1.37m (54in) long whip substituted.

Coil clips are provided which are fastened to the appropriate tapping point on the coil for each band Some care is required when setting the clips so they do not short out adjacent turns. If a short occurs, the effect is to cause an unexplained

HF frequency shift on all bands. This can be cured by fitting small insulating tabs as shown in **Fig 3.12**.

An earth plate, available from the manufacturers, see **Fig 3.13**, will convert the Bugcatcher into a short outdoor vertical. The antenna loaded up quite well with the built-in ATU of the shack TS-850S and I had many QSOs around the UK and Europe on 80 and 40m. If the top whip were replaced with a T shaped wire structure fitted into the apex of the loft, the antenna should work on 160 metres.

The longer the element is below the coil, the more efficient the antenna will be on the lower frequencies.

If you are restricted to a loft antenna, there is nothing to stop you making a similar coil to that described above. Because the coil does not have to be weatherproof you could make the G3UCE coil, described earlier in this chapter, and use it as a loading coil. The size and inductance is not critical provided that taps can be made anywhere on the coil. Shorting out the unused turns with the link from the bottom of the coil to tapping point varies the inductance value.

Fix the coil about halfway up an upright roof support in the loft. Take one wire from the base of the coil to the floor of the loft near to any copper plumbing pipe. Connect the centre of the coax feed to the wire element and the braiding to the plumbing. If there is no plumbing in the loft then use radials as described in Artificial Earths.

Connect a T or inverted L section of wire to the top of the coil and fix to the inside of the roof using insulators; there will be high RF voltages here if you are using a lot of power.

The antenna is set up by adjusting the shorting tap for the lowest SWR for each band using the lowest power possible (or use an SWR Analyser). Wires can then be soldered to the tapping points and marked with the band they are used for.

It is possible to arrange for the tapping points to be switched remotely if you can get high voltage, low capacitance contact relays.

Another possibility is to feed the loft antenna with the G3UCE remote ATU. Setting up would require setting the loading coil to some optimum point.

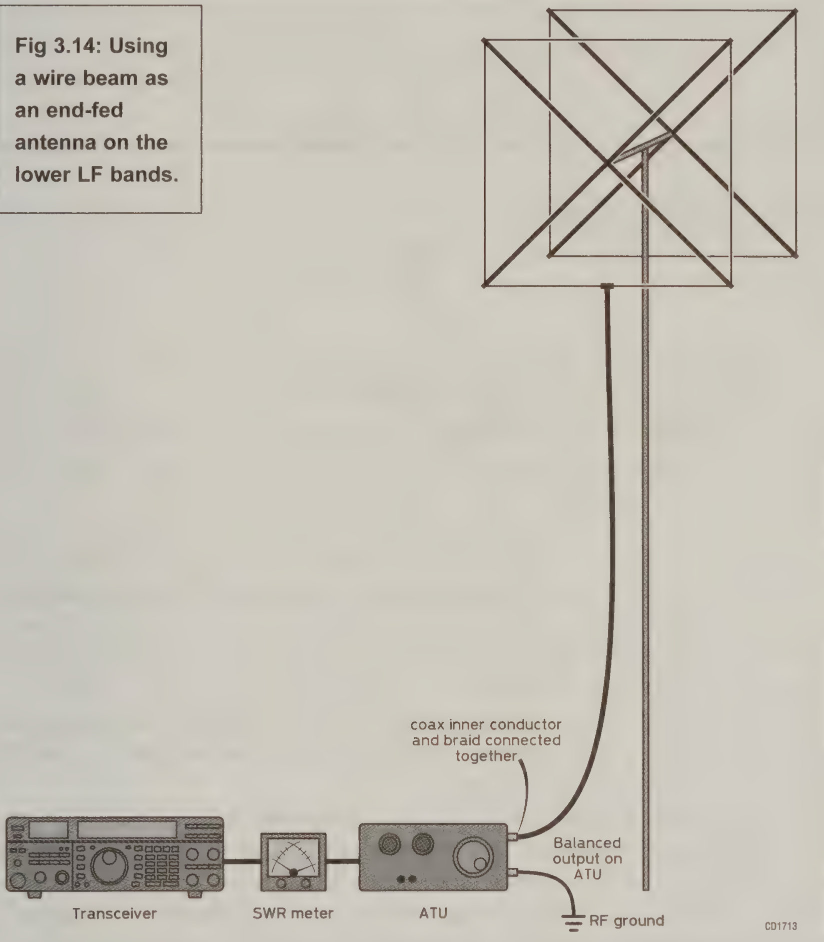
USING AN HF WIRE BEAM ON LOWER HF BANDS

Any wire beam such as the quad, or any of the wire beams shown in Chapter 6, can be used as an end-fed antenna as shown in **Fig 3.14**.

In this case the coaxial cable is used as the antenna conductor rather than as a feeder. The inner conductor and the braid of the coax is shorted together using a PL529 socket with a shorting link and connected to the ATU. The beam itself forms a top capacitance which, provided the coaxial cable is reasonably in the clear, makes a very effective lower HF frequency antenna. I used such an arrangement using the multiband quad described in Chapter 6. This antenna, together with the copper water tank earth mentioned earlier, was used to make regular DX contacts on 80metres.

Other antennas can be used in this way. A dipole for 20metres can be used on the lower frequency bands by connecting the inner and the outer of the coax to the wire antenna terminal of the ATU, as already described, so that the dipole forms a capacity top. A good RF earth is required for this antenna.

Fig 3.14: Using a wire beam as an end-fed antenna on the lower LF bands.



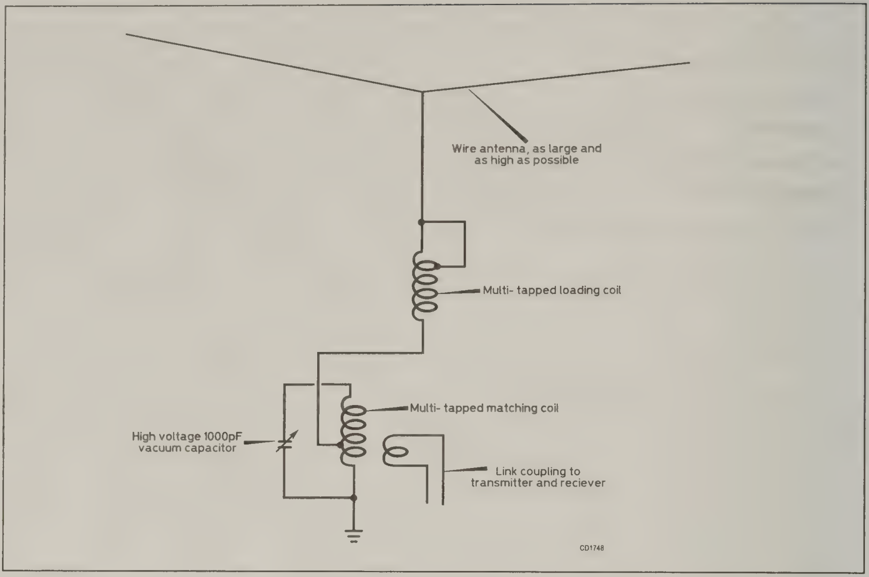
MARCONI ANTENNAS FOR LF

Any antenna that you use from a suburban site on the 136kHz, or 501kHz frequency bands (at the time of writing the latter was available to amateurs in the UK under a Notice of Variation), will almost certainly be electrically small. By that I mean much less than quarter of a wavelength long. A quarter wave end fed antenna fed against earth for 136kHz and 501kHz will 505m and 150m long respectively. However, as already mentioned, electrically short antennas can be made to work using a loading coil and you will need a fairly large inductance to resonate any suburban antenna at this low frequency.

There is nothing particularly special about making an antenna for these bands. In fact you might already have one - an antenna of 80 or 160m will probably work quite well. The most traditional of the LF antennas is the T or inverted L. An 80 or 160m dipole, with both conductors of the feeder shorted makes a good T antenna.

The antenna must be resonated using an inductance of around 5 to 7mH for 136kHz or 1mH for 500kHz, depending on the size of your antenna. The secret of getting an antenna to work on LF is the loading coil and a good earth.

Fig 3.15: An experimental arrangement to use any existing wire antenna for transmitting and receiving 136kHz signals. A better method is to build a variometer into the loading coil and feed the bottom of it via a multi-tapped ferrite cored transformer.


Wire antenna, as large and as high as possible
Multi- tapped loading coil
Multi- tapped matching coil
High voltage 1000pF vacuum capacitor
Link coupling to transmitter and reciever
CD1748

A loading coil for these LF bands needs to be physically large, wound on a plastic bin or similar type of former. The coil can be wound in small multi-layer bunches over the full length of the former, thereby distributing the RF potential gradient over the length of the coil.

To be able to tune the antenna exactly to resonance you need to make the value of the loading coil variable. The traditional method of making a loading coil variable is to use a variometer.

The other method is to use a ferrite core whose position inside the coil can be adjusted, thereby varying the inductance of the coil, as described by G3KAU [5]. By using a ferrite core the coil can be made much smaller but care is required in the construction to ensure that it can stand the high RF voltages on transmit. Some ferrites can be lossy, resulting in the core heating up.

An experimental transmitting arrangement is shown in **Fig 3.15.** The construction of a 136kHz station is, however, beyond the scope of this book and you should consult [5] and [6] for more information on antennas for these bands.

REFERENCES

[1] 'Taming the End-Fed Antenna', Alan Chester, G3CCB, *Radcom* September 1994.
[2] Available from Waters & Stanton.
[3] ‘In Practice’, Ian White, G3SEK, *Radcom* May 1994.
[4] 'Optimum Ground Systems for Vertical Antennas', John Stanley, K4ERO, *QST* December 1976.
[5] *The LF Experimenter's Source Book*, Peter Dodd, G3LDO (RSGB).
[6] *LF Today*, Mike Dennison, G3XDV (RSGB).

4

Matching and tuning

Some of the antennas described in Chapter 2 and all of the antennas in Chapter 3 will require some degree of reactance cancellation and impedance transformation before they can be connected to the station transmitter. A unit for providing this transformation is called an ATU (Antenna Tuning Unit) or Tuner (see Glossary). You will sometimes see terms like ASTM (Antenna System Tuning Unit) or AMU (Antenna Matching Unit) in other publications to describe these devices. In this chapter I will use ATU.

There are three different antenna arrangements that may need coupling to the transmitter:

* The wire antenna fed against earth.
* The antenna fed with coaxial cable
* The antenna fed with twin-line feeder or ladder line

The descriptions of ATUs that follow are classified roughly into Pi or T Network tuner for coax lines, and link-coupled ATUs for balanced lines. The most common arrangement used these days for feeding balanced lines is to use a T Network tuner with a unbalanced to balanced transformer.

SIMPLE ATU FOR END FED ANTENNAS

This is probably the simplest of all ATU circuits and is designed specifically for the end fed antenna. It will match a large range of impedances including the very high impedances to be found at the end half wave or full wave antenna.

In its basic form this ATU is very simple when used for single band operation. I have used the ATU to load a full wave kite antenna for 80 metres. The circuit is shown in **Fig 4.1** and its layout is shown in **Fig 4.2**. The ceramic coil former used is 80mm diameter with 22turns wound over 70mm of its length and tuned with a wide spaced 100pF capacitor.

In practice, the ATU design shown in Fig 4.1 gets rather complicated when multiband operation is required. Ideally, to match a whole range of impedances with all the various lengths of wire that may be encountered, the coil should be tapped every turn. There are three sets of taps to be adjusted for each band. In practice, coil taps can be adjusted on test then fixed so that they can be selected using a switch or relay.

The characteristics of this tuner are narrow band pass, rather than the low or high pass characteristics of the T networks described below. This can be an advantage on receive if there are very strong adjacent signals.

Fig 4.1: A circuit diagram of an ATU for a multiband end-fed antenna. Ideally, to match a whole range of impedances of an end-fed antenna, the coil should be tapped every turn. In practice, a limited number of coil taps can preset and selected using a clip or a switch. The three coil taps and the capacitor settings have to be changed for each band.

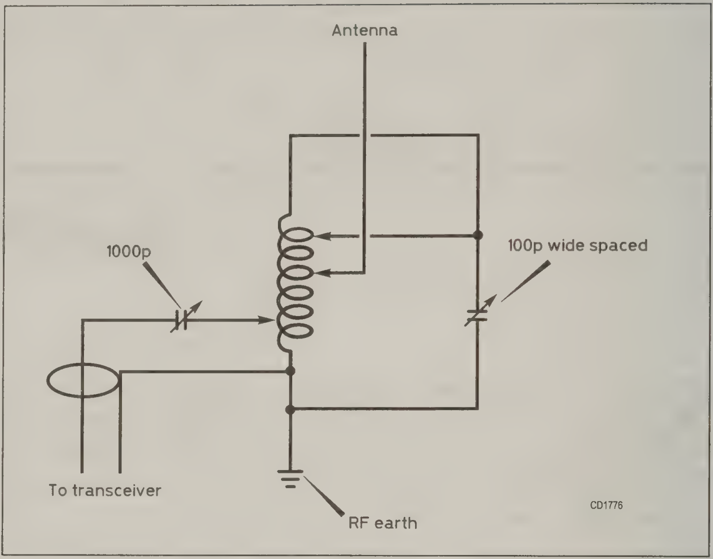
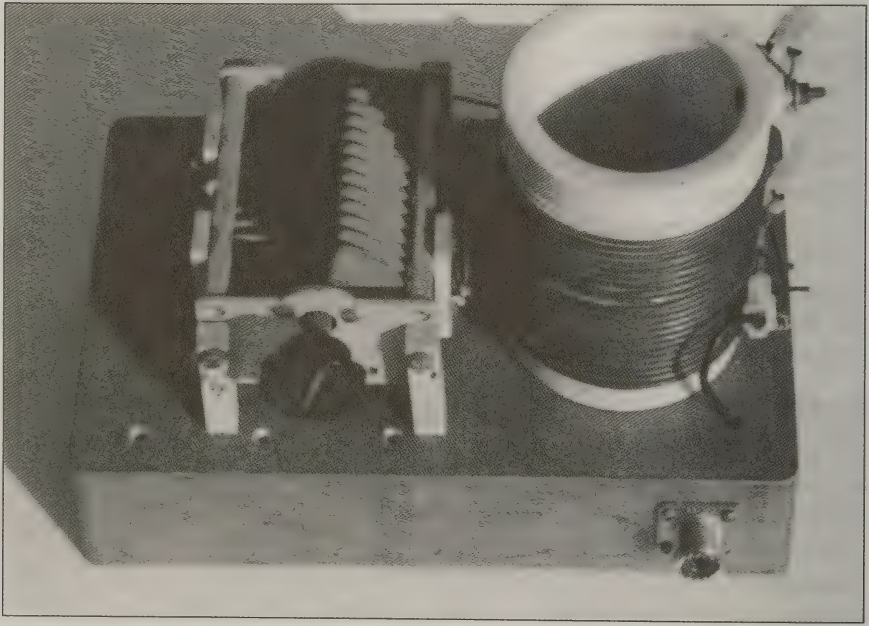


Fig 4.2: A single band ATU for 80m. The coil comprises 22 turns wound on a 80mm diameter former. The parallel capacitor and taps are preset and the This ATU was used remotely in the garden shed.



THE T-NETWORK ANTENNA TUNER

The classic pi-network or LC/CL two-component matching networks can be used as the basis of an antenna tuning unit (ATU). These are theoretically capable of matching any transmitter to any antenna impedance (resistive or reactive). However, in practice the matching range is dependent on the component values. For the widest step-up and step-down transformations, the high-voltage variable capacitors need to have low minimum and very large maximum capacitance values. This is a significant disadvantage with variable capacitors in manual ATUs but less of a problem with automatic ATUs with their relay switched fixed capacitors and inductors. The Pi-network and some of the standard LC

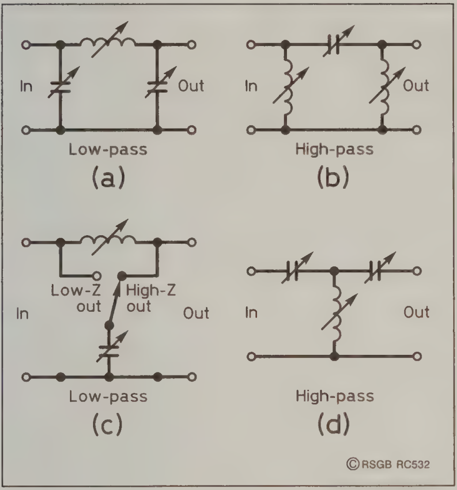
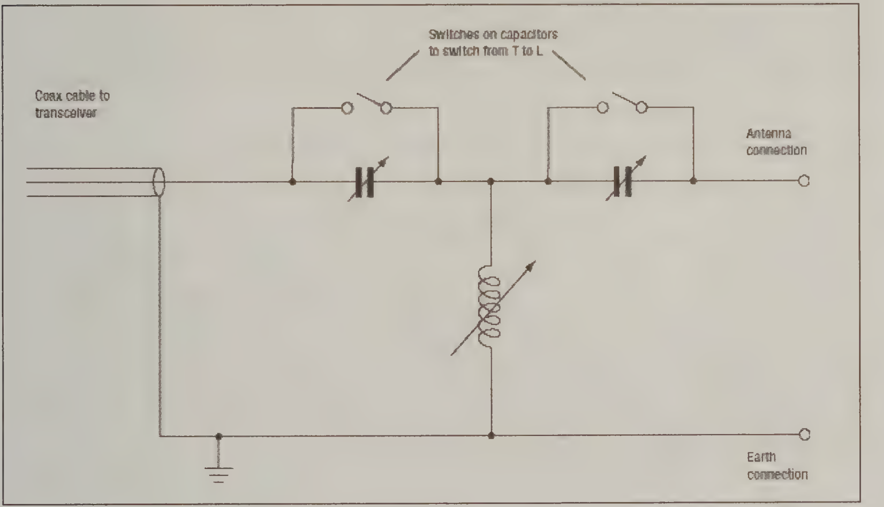


Fig 4.3: Some basic ATU configurations. (a) P1-network in conventional 'low-pass' form. (b) Inverse pi-network with components interchanged but providing high-pass filter. (c) Switched LC network providing either step-up or step-down of the Impedance with a degree of low-pass filtering. (d) T-network (high-pass).

Fig 4.4: The series capacitor T network, which form the basis of most modern ATUs. The shorting switches across the capacitors allow the unit to be switched to an L network to widen the range of impedance matching


Switches on capacitors to switch from T to L
Coax cable to transceiver
Antenna connection
Earth connection

configurations, see **Fig 4.3**, do however possess the advantage that they not only transform impedance but also form a low-pass filter; and so provide additional harmonic and higher frequency spurii attenuation.

While the T match has enjoyed considerable popularity it does suffer losses on some transform ratios on the higher frequencies. These losses can be minimised by a simple modification, see **Fig 4.4**, which uses a cam switch on the end of each of the capacitors and is described in more detail in [1].

COMMERCIAL MANUAL T TUNERS

The MFJ 901

Some time ago I wanted a small ATU to take on vacation for use with my Icom IC-706. I tried to make one but was really stuck for the right size components. I finished up buying the MFJ-901 from MFJ (see Appendix).

It uses a T-match tuning arrangement described above with air-spaced capacitors and a switched large diameter air-spaced inductance. The MFJ-901B,

Fig 4.5: Layout of the MFJ 901 ATU.

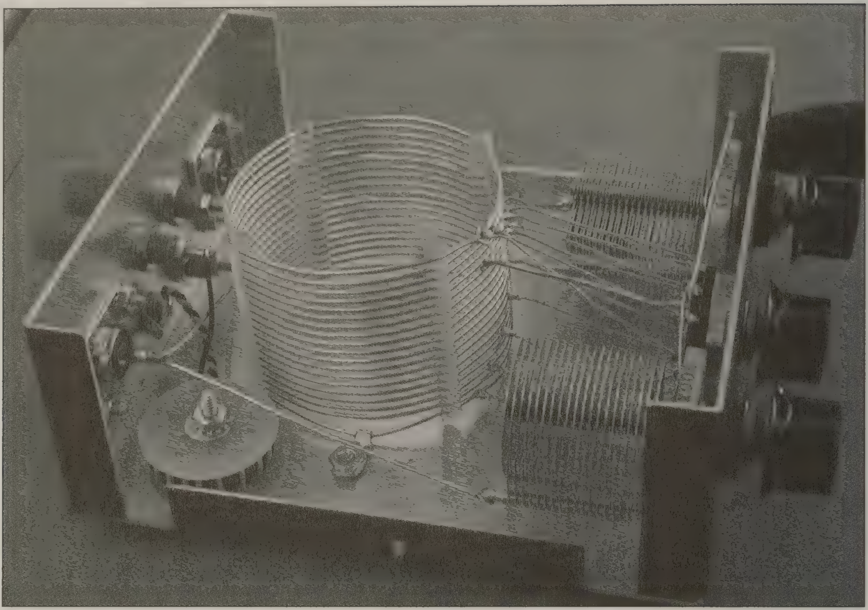
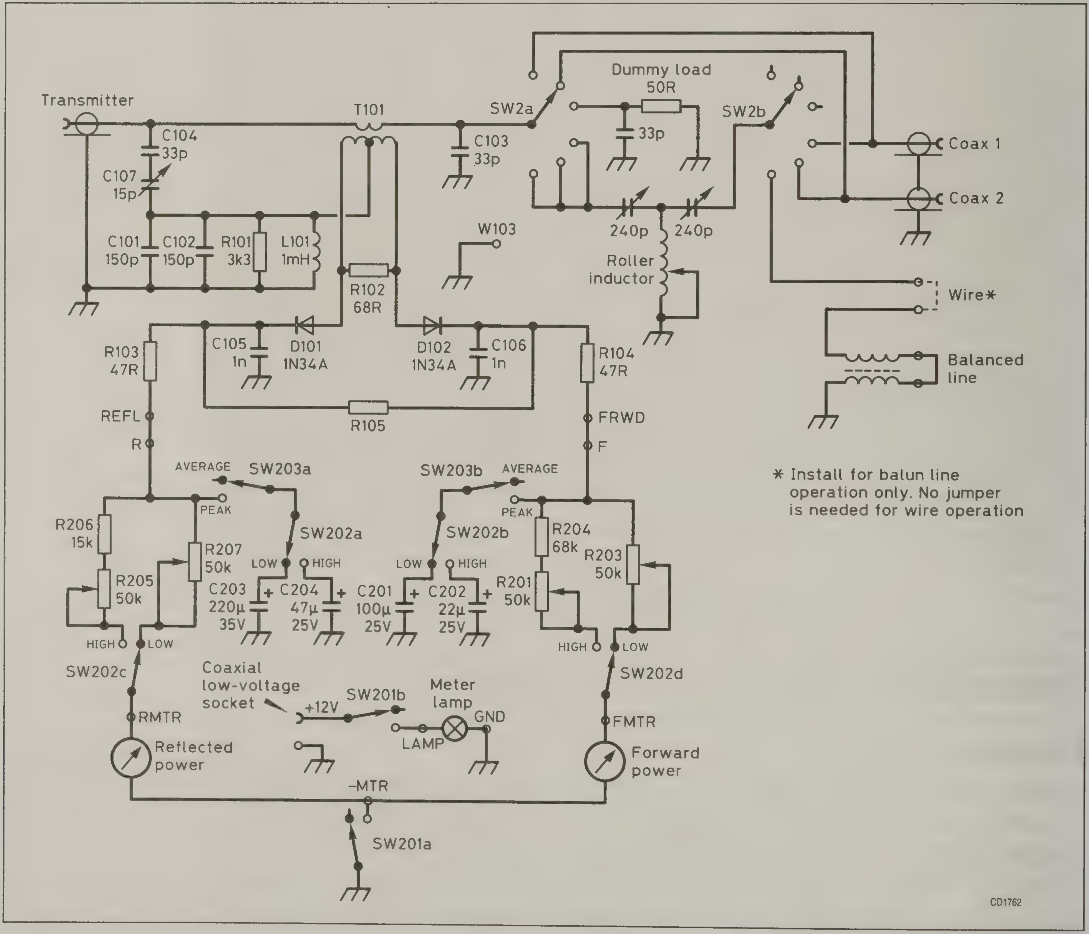


Fig 4.6: Circuit diagram of the MFJ-989C VersaTuner V.



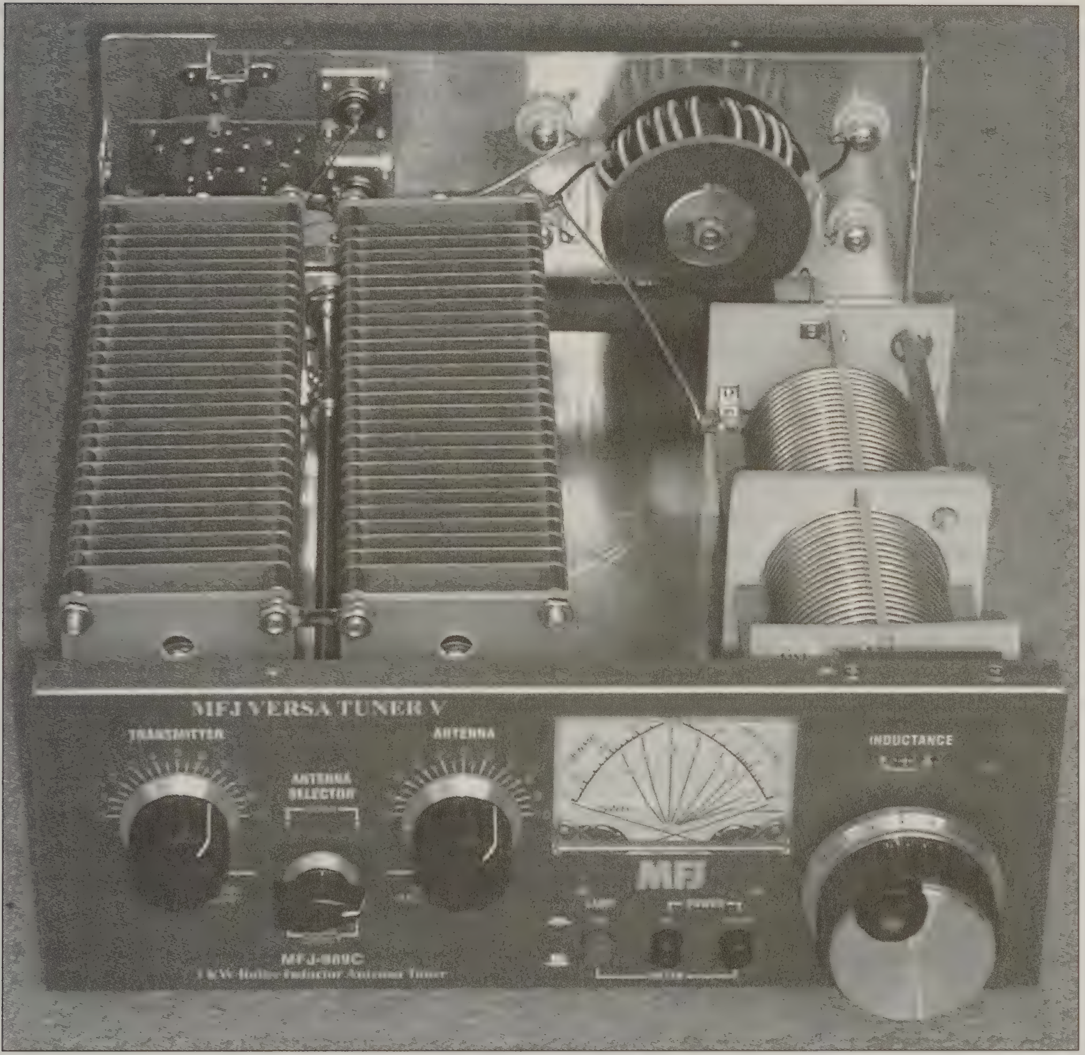


Fig 4.7: Layout of the MFJ-989C VersaTuner V.

see **Fig 4.5**, is not much larger than a FT-817 transceiver and weighs only 600gm. It uses a transformer balun at the output for use with balanced feeder antennas and in fact I used it this way and it worked very well with the portable antenna described in Chapter 3.

The MFJ 989C VersaTuner V

At the other end of the power scale is the MFJ-989C. It again uses a T-match tuning with with very large air-space capacitors. The inductor is a 'roller coaster' with a position counter that allows the inductance to be set very accurately. It uses an switching arrangement for selecting either one coaxial fed antenna of two. It can also select a long wire or balanced feed antenna when the toroid balun is linked in. It also has a cross-needle power and SWR meter. The ability to switch in a dummy load is also a useful feature. In fact this is more than an ATU - it is an antenna management system. The circuit and layout of the MFJ-989c is shown in **Fig 4.6** and **Fig 4.7** respectively

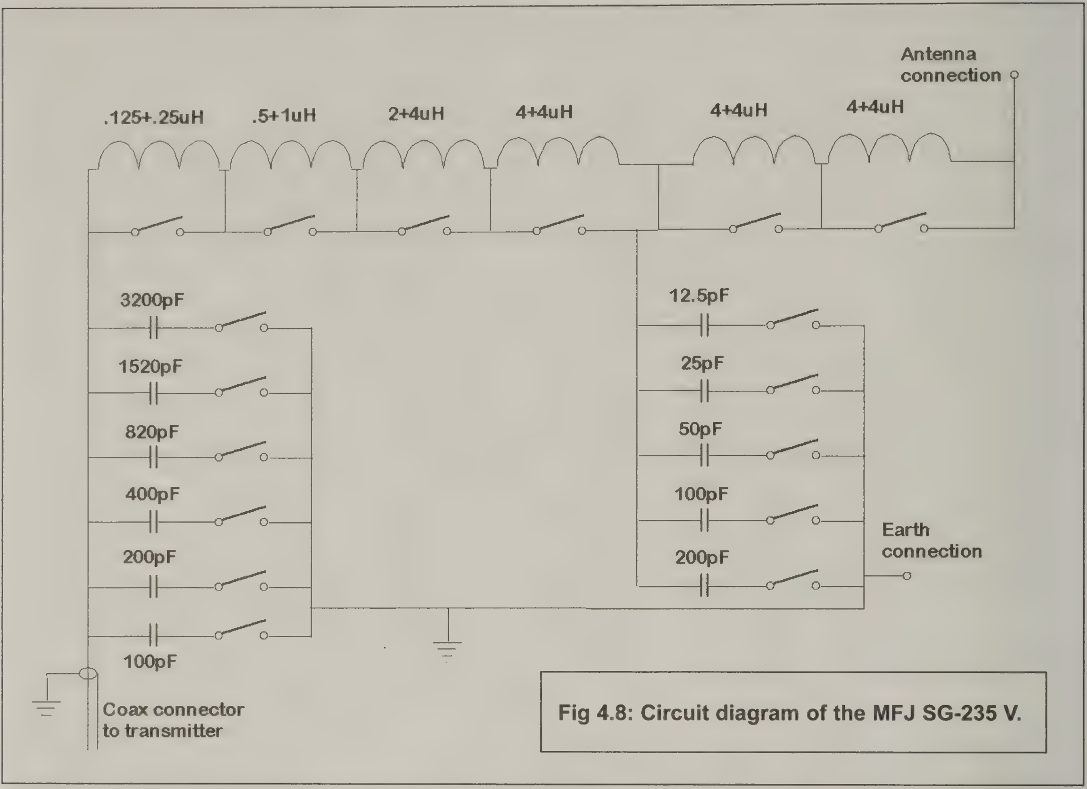


Fig 4.8: Circuit diagram of the MFJ SG-235 V.

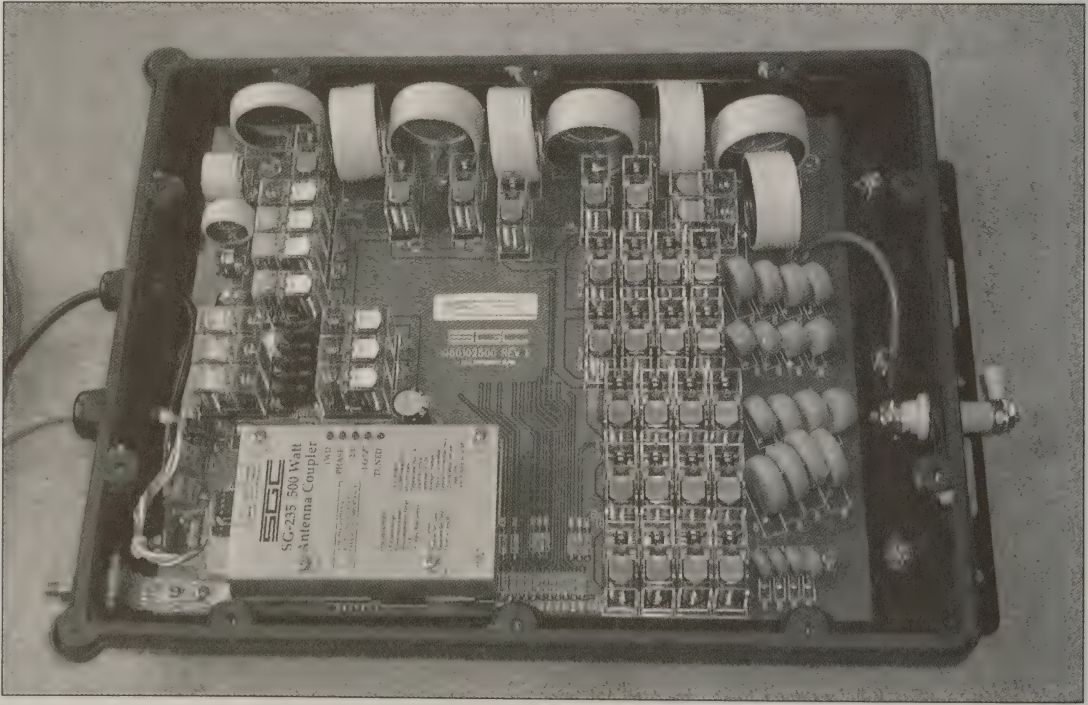


Fig 4.9: Layout of the MFJ SG-235 V.

AUTOMATIC ATUs

The automatic ATUs now on the market have made the remotely fed antennas a much more practical reality. Furthermore, they are not as expensive as they used to be. Most commercial automatic ATUs use T matching with the adjustment of the inductors and capacitors in the matching network being accomplished using relays. These relays are controlled via a microprocessor using an embedded tuning algorithm, which in turn receives SWR and impedance samples from an RF head.

The SG-235 is quite a robust unit said to be capable of handling 500W; a simplified circuit is shown in **Fig 4.8**. From this we can see that the SG-235 is a Pi-network although if one of the banks of capacitors were switched out it would become an L network.

On the left hand side of Fig 4.8 are the capacitors associated with the low impedance, 50 ohms, input from the transmitter. This bank of capacitors, with a total capacity of over 6000pF, can be switched in or out with relay contacts with a resolution of 100pF. On the antenna side of the ATU a total of nearly 400pF can be switched in with a resolution of 12.5pF. These capacitors are made up of groups of series/parallel capacitors to obtain a safe voltage working.

Additionally, these capacitors are switched using four sets of relay contacts in series for both switching voltage working and to reduce stray capacitance. The construction of the SG-235 is shown in **Fig 4.9**. The Pi section inductor (the section between the capacitor banks) is actually made up of eight inductors having a total inductance of 15.75μH and a switching resolution of 0.125μH. Antennas shorter that a quarter wavelength, which present low and capacitively reactive impedances are taken care of using four 4μH inductors (top right) that can be switched in or out to load a short antenna.

The construction of an automatic tuner is beyond the scope of this book, however the G3XJP PicATUne automatic ATU design can be found at [2]

For outdoor use, such as matching an antenna remote from the shack, the ATU circuits must be protected from the weather. The MFJ- 927 shown in **Fig 4.10** is an example. This unit has an additional feature: power for operating the circuits of the ATU can be fed to it through the coax feeder thus removing the need for a separate supply line.

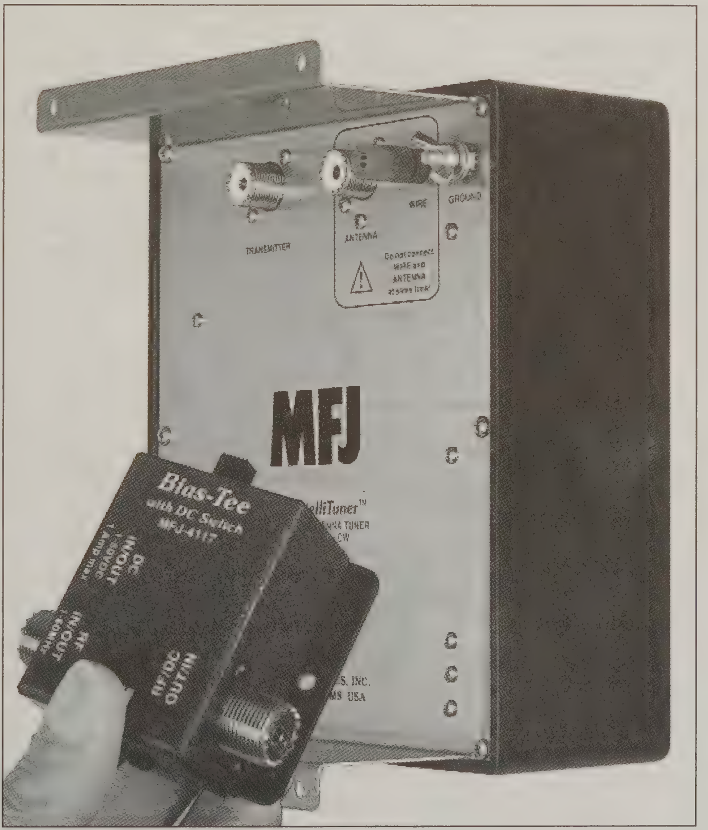

TRANSMITTER
ANTENNA
WIRE
GROUND
Do not connect WIRE and ANTENNA at same time!
MFJ
IntelliTuner™
Bias-Tee with DC Switch MFJ-4117
DC IN/OUT
RF IN/OUT
RF/DC OUT/IN

Fig 4.10: The MFJ 927 automatic ATU with protective weatherproof housing. The Bias Tee box allows the supply voltage for the 927 to be fed into the coax cable at the shack. [Photo courtesy of Waters & Stanton]

THE G3TSO TRANSMATCH

The following is a description of how to construct a T-match ATU by M J Grierson, G3TSO [3].

This tuning unit provides operation on all bands from 1.8 to 28MHz. Other features have been added to permit the selection of different antennas as well as the facility to ground all inputs when the station is not in use. This unit also includes an SWR meter, and a balun to allow the unit to feed balanced lines. You may not wish to include all these features. The circuit diagram is shown in **Fig 4.11**.

Component selection

New components suitable for use in antenna tuners are not readily available or very expensive, so the use of surplus components is the most economical answer. Fortunately the values of capacitors required are not too critical, and almost any high-quality wide-spaced variable capacitor can, be put to use. Ideally a value of between 200pF and 400pF is suitable, and a number of surplus Johnson and Eddystone 390pF units have been seen over recent years. These units have ceramic end plates and are tested to 2,000V DC working. If in doubt, aim at a plate spacing of at least I .5mm between the stator and rotor plates; this is necessary to cope with the high voltages which can be developed when matching high-impedance long-wire antennas.

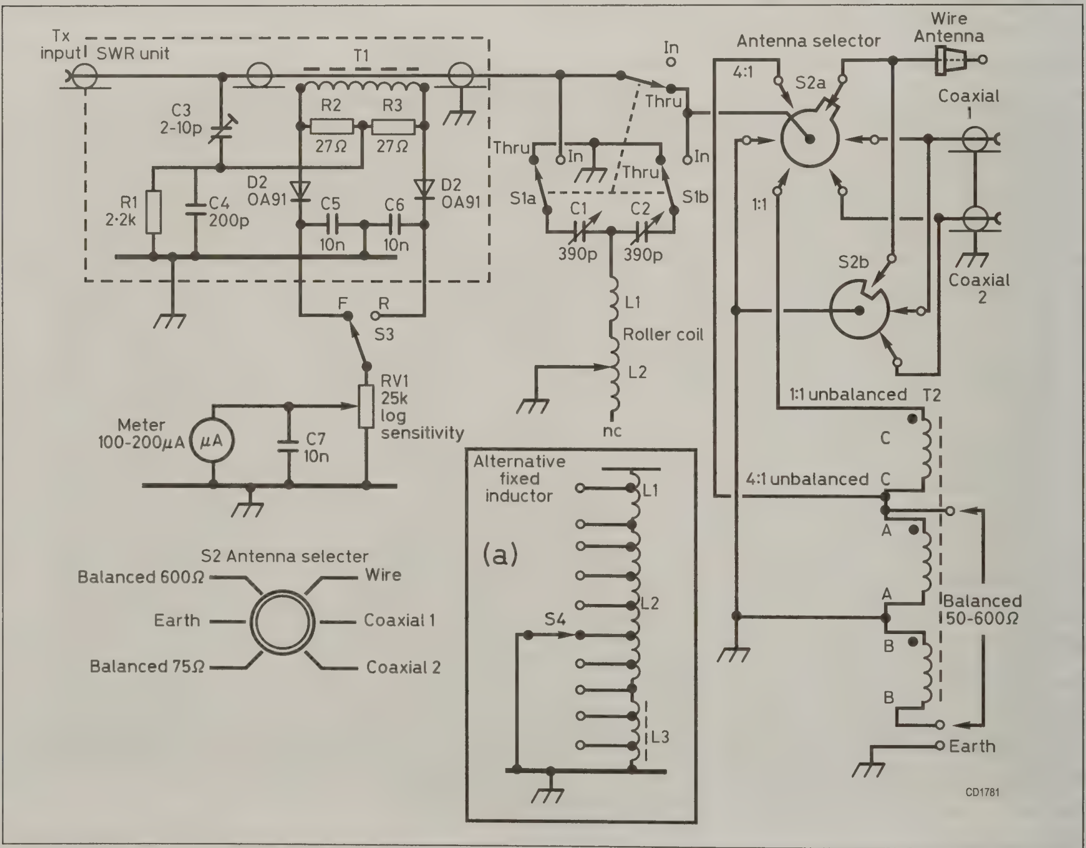


Fig 4.11: Circuit diagram of the G3TSO ATU.

Inductors can be either fixed with a number of taps selected by a rotary switch, or variable such as the roller coaster, which allows maximum flexibility in matching. Roller coasters come in a variety of different shapes and sizes, but in general are not available in other than small numbers and one-offs.

All switches used are of the 'Yaxley' type and use ceramic wafers; large numbers of this type of switch can often be found in junk boxes at rallies, and several switches can be broken down and reassembled to achieve the desired configuration. Paxolin wafers can be used, though they are not as good as the ceramic type.

The antenna selector switch uses a double-spaced switch unit giving six stops/revolution rather than the usual 12. The switch wafers are modified by removing alternate contacts, thus reducing the likelihood of arcing between them.

Balanced feeders

As the T-match is an unbalanced antenna tuner, some type of balun transformer must be incorporated if it is to be used successfully with balanced feeders. While a balun transformer provides a very simple solution for coupling a balanced feeder to an unbalanced tuning unit, it is not likely to be as efficient as a properly balanced ATU. Many published designs use a 4:1 balun to provide a balanced input for impedances in the range 150 to 600 ohms. However, if a low impedance feeder from either a G5RV or W3DZZ type of antenna is connected to a 4:1 balun, significant losses may occur. For this reason it was decided to use a 1:1 balun which, if fitted inside the tuning circuit, can easily be switched to 4:1 by use of the antenna selector switch. This now provides a range of balanced inputs from about 45 to 600 ohms without introducing too many losses into the system.

Balun construction

Full details of the construction of a suitable 4:1 balun can be found in Chapter 3, in the section on the PA0SE Comudipole antenna.

SWR measurement

It is often convenient to be able to connect the antenna tuner directly to the transmitter without the need for extra cables and external SWR bridges, so a built-in SWR bridge has been included in the design. The circuit, shown in **Fig 4.12**, is fairly conventional and is of the current-sampling type of bridge which, unlike the voltage sampling stripline type of bridge, is not frequency conscious.

The current transformer T1 uses a small ferrite ring of about 12mm (0.5in) diameter, and while the size is not critical, the grade of ferrite is. Ferrite having an AL value of at least 125 should be used, and the Amidon FTSO-43 ferrite core is ideally suited to this application.

A short length of coaxial cable is passed through the ferrite core to form the primary after the 18 turn secondary has been wound on. The braid of the cable can be earthed at one end to form an electrostatic screen, but on no account should both ends of the braid be earthed or it will form a shorted turn.

The diodes Dl and D2 should be a matched pair of germanium diodes, which can be selected from a number of similar-type diodes by comparing

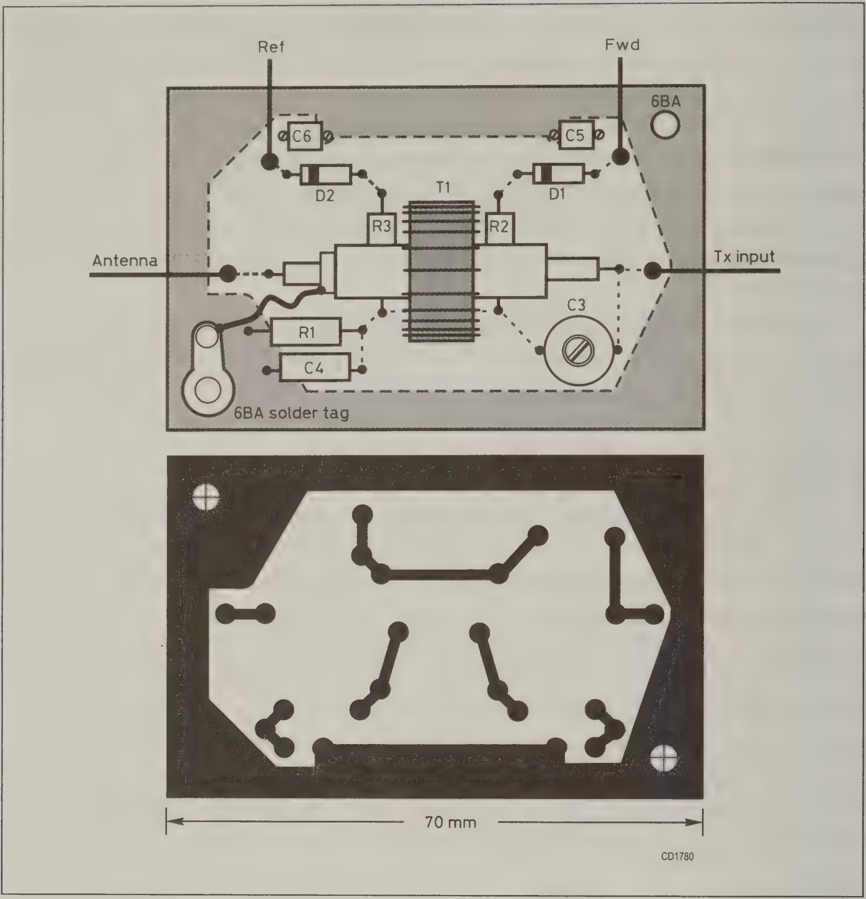


Fig 4.12: PCB and layout for the SWR bridge.

their forward and reverse resistances. While this is best done with a high frequency signal, adequate matching can be achieved by using a simple multimeter.

Fig 4.12 gives a suggested layout and PCB track. The size is not at all critical, but a symmetrical layout should always be attempted.

The completed SWR bridge should be tested away from the antenna tuner by placing it in line between a suitable transmitter and a 50 ohm dummy load. The trimmer capacitor is adjusted to produce a zero-reflected reading with the forward reading at full scale.

By connecting the bridge the reverse way around, some check of the diode balance can be judged by comparing the meter deflections in both directions. The forward and reverse switch selection will be reversed if the signal direction through the bridge is reversed. It is advisable to check that the bridge balances on a number of different bands, as C3 may be more sensitive at the higher frequency end of the operating range.

The sensitivity of the bridge is very dependent upon the resistance of the meter used. Comparison with a calibrated SWR bridge will enable a simple calibration of 1.5:1, 2:1 and 3:1 to be made, and in most cases a mental note of where these occur is the only calibration required, unless you wish to dismantle the meter in order to recalibrate the scale.

Construction of the antenna tuner

The complete tuner layout is illustrated in **Figs 4.13 and 4.14**. It is advisable to collect all the components and lay them out on a sheet of paper before committing oneself to a particular size.

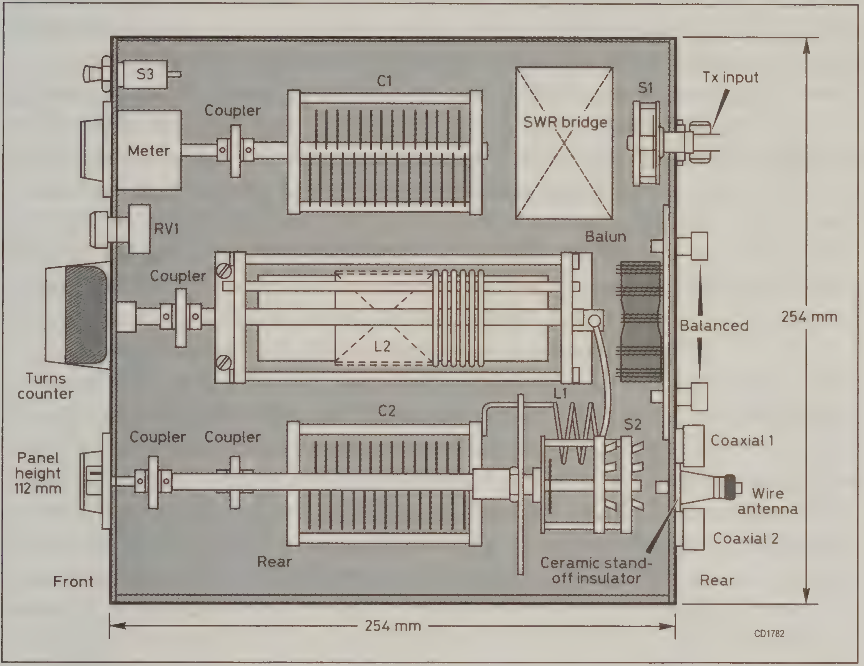


Fig 4.13: Component layout of the G3TSO ATU.

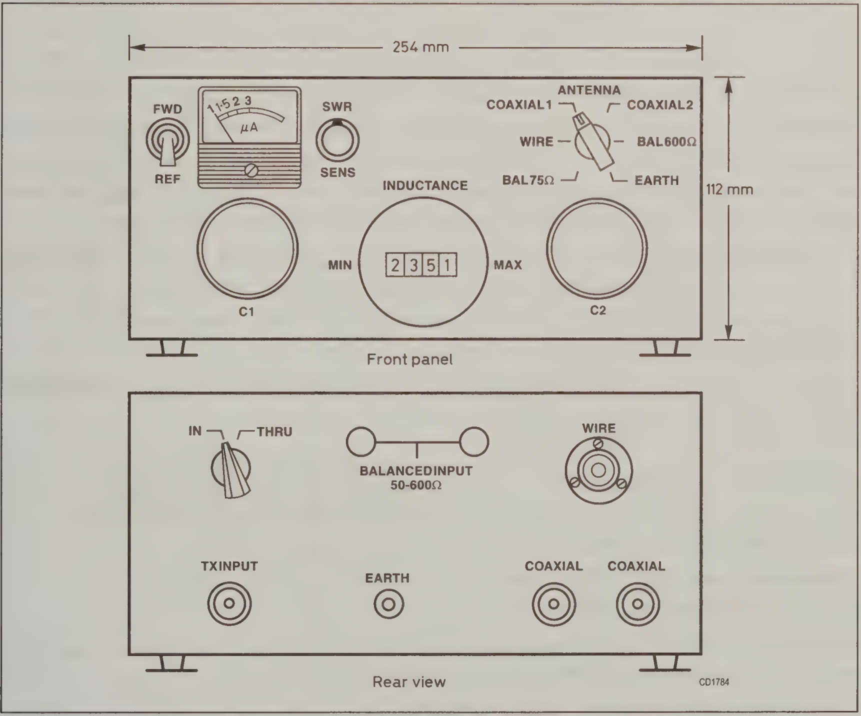


Fig 4.14: Front and rear panels of the G3TSO ATU.

Layout is not over-critical, but a sensible approach is needed to minimise lead lengths and unnecessary stray capacitance, which could render 28MHz operation impossible.

Cases can be purchased, or prefabricated using 16 or 18SWG aluminium sheet bent into two interlocking 'U' shapes. Half-inch aluminium angle provides stiffening as well as a means of joining the sections together. Roller coaster connections should be arranged so that minimum inductance is located at the end closest to the connections, ideally the rear of the unit. A small heavy-duty coil, L1, is included for ease of 28MHz operation and is more efficient than half a turn on the roller coil. An alternative arrangement to the roller coaster is shown in Fig 4.11. Here a switched inductor is used. The switch should be of the ceramic type with substantial contacts. A third toroidal inductor is included to permit operation on 1.8MHz, and it is recommended that the bottom end of this could be shorted to ground to prevent the build-up of high voltages which could arc over.

A further switched inductor, described by G3OHK is shown in **Fig 4.15**.

The capacitors C1 and C2 are electrically above ground and must be mounted on insulators, a problem greatly reduced if the capacitors are constructed using ceramic end-plates. Ceramic pillars or even Perspex may be considered for mounting capacitors with metal end-plates. Additionally the shafts of the capacitors must be insulated, and the use of Eddystone spindle couplers is recommended. To ease the rather sharp tuning characteristics that can be encountered on 21 and 28MHz, slow-motion drives were tried but they made tuning on the lower frequencies rather laborious and their use is not advisable. A turns counter on the roller coaster makes for much simpler operation, and may be as simple as a slot in the cabinet with a Perspex window for monitoring the position of the jockey wheel or a more sophisticated geared or direct-drive counter.

Antenna switching can introduce excessive lead lengths as well as stray capacitance. For this reason the antenna selector switch is located on an extension shaft at the rear of the unit, adjacent to the antenna inputs and the balun transformer. The wiring of the antenna switch is done strictly to achieve minimum lead lengths rather than to provide front-panel selections in any logical order. A separate IN/THROUGH switch enables the tuner to be bypassed and the antennas routed directly to the transmitter. It is located on the rear panel adjacent to the input socket to minimise lead length, and is intended for only occasional use. It is necessary to ground the tuning components in the THROUGH position to minimise capacitance effects.

Wiring of the tuner should commence after the mounting of all components. Fairly heavy wire such as 16SWG tinned wire, coaxial cable braid or copper strip should be used. It has

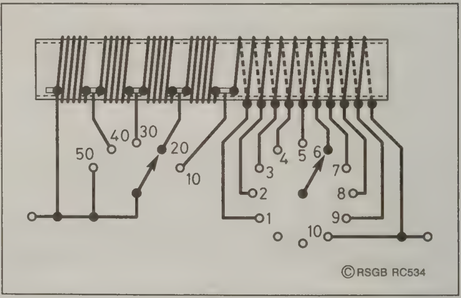


Fig 4.15: A variable inductance ATU coil described by Hector Cole, G3OHK. This arrangement uses two switches and just 14 taps to permit selection of from one to 50 turns of a 50-turn coil and which can be quickly reset to any number of turns previously found suitable without the turns counters required for roller coaster coils.

not been found necessary to screen the SWR bridge, but it should be located directly adjacent to the transmitter input socket and all meter leads kept away from tuning components.

The antenna selector switch has two ceramic wafers and is arranged so that every other contact is removed to give double spacing. The second wafer is used for shorting and provides a ground for all unbalanced antennas not in use, and is largely to prevent capacitative coupling to other antennas. The balanced input is grounded to DC through the balun. Balun switching is simply achieved by either taking the input from one side of the balanced input, giving a 4:1 ratio, or by selecting the third winding, giving a 1:1 ratio. An earth position enables the transceiver input to be grounded to prevent static discharge into the receiver.

Operation of the antenna tuning unit

If the SWR bridge is included in the design it should be checked and balanced independently of the ATU, using a dummy load, and ideally be compared and calibrated against an SWR measuring device of known accuracy.

To use the antenna tuner, select the required antenna and ensure that the THROUGH/IN switch is in the IN position. Set both Cl and C2 to halfway positions, adjust the inductance for maximum signal on receive, and one at a time adjust Cl and C2 for maximum received signal. Using low CW transmitter power, further adjust Cl, C2 and the inductance to eliminate any reflected reading on the SWR meter. All tuning controls are interdependent, and settings may need to be adjusted several times before minimum SWR is achieved. In addition, more than one setting may give a matched condition, in which case the settings requiring the highest value of Cl should be used. Once the transmitter is matched on low power, increase to the operating power for any final adjustments. Never attempt to tune the ATU initially on full power or with a valve power amplifier that has not been tuned up.

Generally, the higher the frequency the lower the value of inductance required, but exceptionally high impedances may require more inductance than expected. Capacitance values may vary considerably, and it is not uncommon on the higher frequencies for one capacitor to be very sharp and require a minimum value while the other is flat and unresponsive. Using the components recommended it is possible to match a wide range of impedances from 1.8 to 28MHz, but operation on 1.8MHz may become impossible if lower values of capacitance are used; however, fixed silver mica capacitors may be switched across Cl and C2 to compensate. Higher values of capacitor will almost certainly prevent operation on 28 and maybe 14MHz.

Conclusion

The antenna tuner described is not new, nor revolutionary in design, but probably represents the ultimate in flexibility. Performance is good and it is not inhibited by a lack of balanced input or restricted to a very narrow range of low impedances. The power handling capability of the tuner will to a large extent depend upon the impedances encountered and the spacings of the capacitors. As a rule, very high impedances should be avoided, as arcing can occur in the switches and the efficiency of the unit may well suffer. Adjustment of antenna or feeder length can remove any exceptionally high impedances that may be encountered.

G3TSO used this tuner with a 60m (180ft) doublet fed with an unknown length of 300-ohm slotted ribbon feeder, where it could be tuned to give a 1:1 SWR on all amateur bands from 1.8 to 28MHz. Using Eddystone capacitors of the type recommended, the tuning unit should be capable of handling 100W into a fairly wide range of impedances up to several thousand ohms, and the full 400W into impedances up to 600 ohms.

Two versions of the tuner have been built using the same basic circuit, one for base station operation using a roller coaster coil, and a smaller portable version using a range of switched inductors. The portable version has a slightly different layout, largely as a result of trying several other designs. Combining the IN/THROUGH facility on the inductor switch has necessitated several wafers. The balun used in this version is also the simpler 4:1 type and is connected with a flying lead.

The construction of the described antenna tuning unit should be well within the capabilities of most newly-licensed amateurs, and it can represent a considerable financial saving when compared to the commercial alternative.

G3TSO ATU Components list

ATU	
C1, C2	390pF 2,000VDC wkg, ceramic end-plates, eg Eddystone or Jacksons
L1	3t 10SWG, 25mm (l in) ID, 25mm (l in) long
L2	Roller coaster 36 turns, 38mm (1.5in) dia 16SWG
T2	Amidon T200-2 (red); 14 turns trifilar 16SWG enamel
S1	Three-pole two-way ceramic Yaxley
S2	One-pole six-way double-spaced ceramic Yaxley One-pole six-way shorting water (one pole open)
Alternative ATU circuit	
L1	2.5t 14SWG 25mm (1in) ID tapped at 1.5t
L2	l4t l6SWG 1.25in ID tapped at 1, 2, 6, 9 and 14t
L3	Amidon T1 57-2; 31t l8 SWG enam tapped at 6 and 27t
S4	One-pole 11-way ceramic (three wafers to include S1 function)
SWR bridge	
R1	2.2k
C3	2-10pF trimmer
C4	200pF mica
CS, C6, C7	10nF disc ceramic
R2, R3	27Ω
RV1	25k log
D1, D2	Matched OA9l etc (germanium diodes)
T1	18t 22SWG 13mm (0.5in) OD ferrite ring (Amidon FT50-43, Fairite 26-43006301). Primary: 38mm (1 5in) coaxial cable, braid earthed one end only to form electrostatic shield.
Meter	100-200µA
S3	SPCO miniature toggle

BALANCED ATUs

Many of the antennas described in Chapter 3 require a balanced twin-wire feed. Some of the unbalanced antenna tuners (ATUs or transmatches) so far described have a 4:1 balun at the antenna output side of the tuner, to convert the balanced line to an unbalanced line.

A 4:1 balun can reduce the already low impedance at the antenna terminals to a still lower one, and high reactances are often unfriendly to the cores used in such baluns. However, the balun used in the G3TSO design, described earlier in this chapter, uses a ratio of 1:1 in addition to the 4:1 ratio, which can mitigate the problem to some degree.

So just what is balance and is it important?

Early radio stations used open wire feeders coupled to the tank circuit of the transmitter in such a manner that the currents in each of the wires of the feeder were equal and opposite. This it what is meant by 'balanced', and a balanced line ensures the feeder does not radiate. This was particularly important with commercial stations where the antenna could be some considerable distance from the transmitter and radiation from the feeder could result in considerable loss of RF power. In the case of an amateur installation, where the feeder lengths are relatively short balance may not be such an issue.

Because amateur practice tended to follow commercial practice, many amateur operators in the past went to a lot of trouble to ensure that the current in each of the feeder lines was equal. This was done by providing methods of adjusting the coupling circuit for equal current. A current meter in each of the conductors of the feeder was used to monitor the balance. They also gave an indication of maximum current when tuning.

The classic method of achieving balance is a link-coupled or inductively coupled ATU; the basic circuitry is shown in **Fig 4.16**. The unbalanced input is inductively coupled to the main inductor. Since the mutual inductance between the coils is critical for maximum efficiency, the coupling is varied either by a movable link or by a series input capacitor.

Likewise, a single coil and link for all HF bands does not provide the best coupling ratios for all possible conditions. Without provision for coil tapping and series connections, the most efficient operating mode may be inaccessible, despite a 1:1 match.

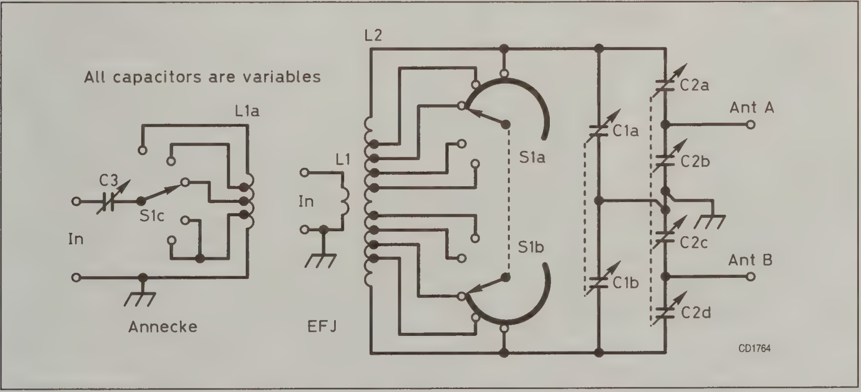


Fig 4.16: Typical link-coupled antenna tuner circuit.

COMMERCIAL BALANCED LINE TUNERS

The early commercial units were the Johnson Matchbox and the Annecke (made in Germany). A simplified diagram of these units is shown in **Fig 4.17**.

The Johnson Matchbox circuit is a straightforward link-coupled circuit. The input with the relay and associated circuitry includes taps for a 50-ohm transmitter connection and a 300-ohm receiver connection, since receivers continued to used balanced input strips long after transmitters had gone to shielding, pi networks, and 50-ohm outputs. The Johnson Matchbox used a single link for all bands with no variability.

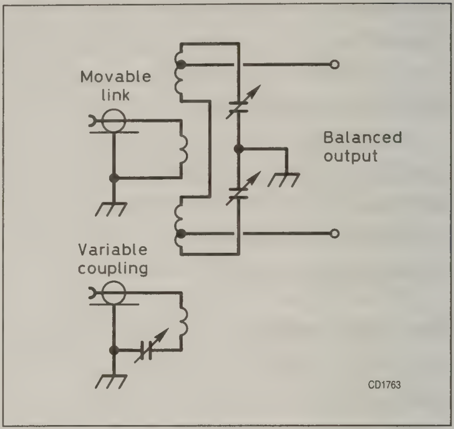


Fig 4.17: Simplified diagram of the Johnson and Annecke link-coupled tuning units.

The MFJ 947 balanced tuner

The MFJ-974 is different. It comprises a double T-Network arrangement to provide a fully balanced wide range ATU. The tuning components are mounted symmetrically, see **Fig 4.18**, to maintain electrical balance. To ensure symmetry over the tuning range it uses four gear driven 1000-Volt air variable capacitors.

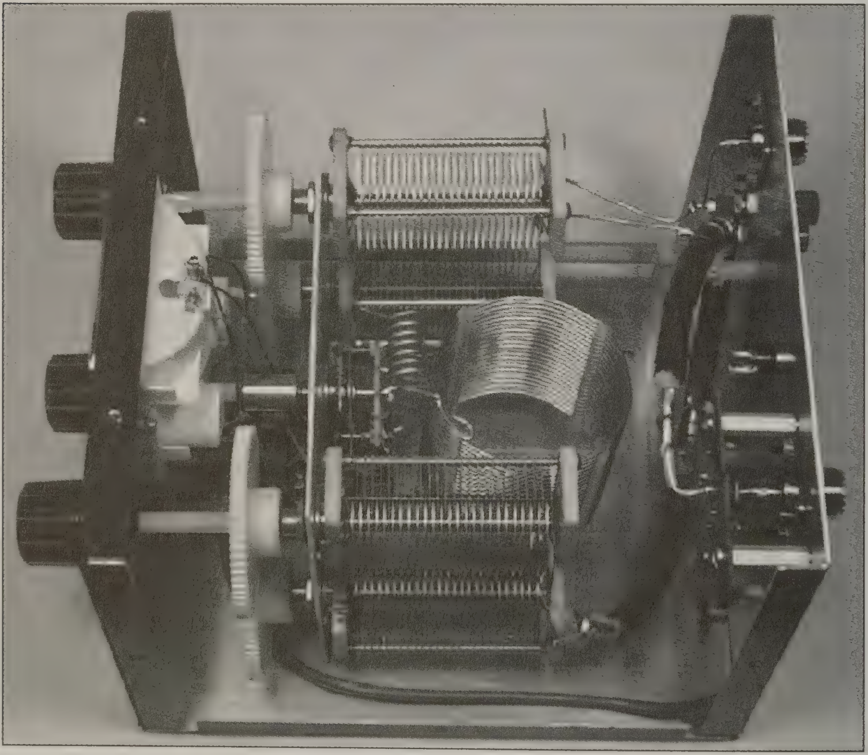


Fig 4.18: Layout of the MFJ 947.

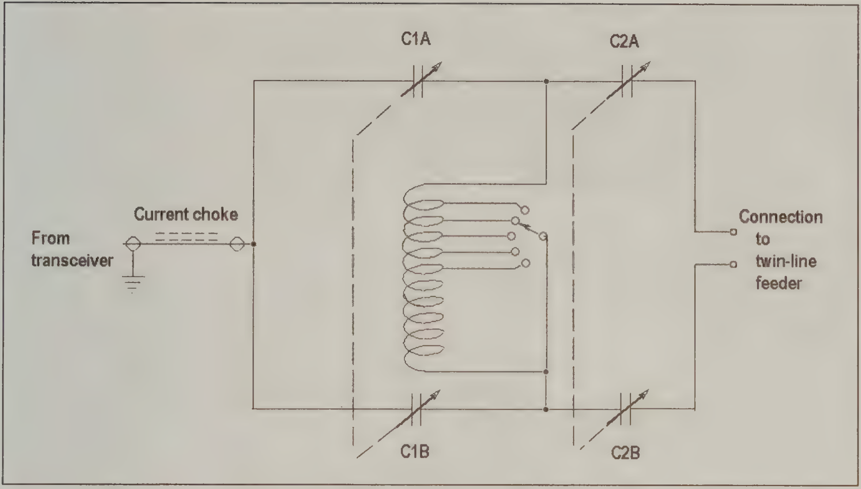


Fig 4.19: Circuit diagram of the MFJ 947.

The inductance is a high-Q air wound tapped inductor for 80-10m with separate inductors for 6 and 160m. The circuit is shown in **Fig 4.19**.

A 1:1 current balun is placed on the low impedance 50 ohm input. The balun is made of 50 ferrite beads on RG-303 to give efficient isolation.

THE Z-MATCH

Another link coupled ATU that has been around a long time is the Z-match. Originally it was designed as a tank circuit of a valve PA, the anode of which was connected to the top or 'hot' end of the multiband tuned circuit. It was fed directly from the PA valve, with its internal (source) impedance of several thousand ohms

When the circuit was adopted as an ATU the tank circuit was fed directly from a source which requires a 50 ohms load via a 350pF variable coupling capacitor connected to the top (or 'hot') end of a multiband parallel-tuned LC circuit, see **Fig 4.20**.

In spite of the great disparity between the required 50 ohms load for the transmitter and the relatively high impedance of the tank circuit, the Z-match enjoyed considerable popularity, probably due to its simplicity. Z-match ATUs

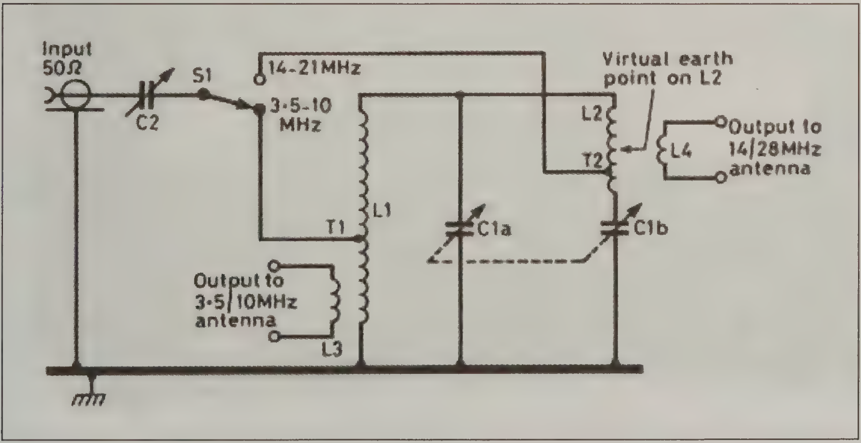

Input 50Ω
C2
S1
14-21MHz
3·5-10 MHz
Virtual earth point on L2
L2
T2
L4
Output to 14/28MHz antenna
L1
T1
C1a
C1b
Output to 3·5/10MHz antenna
L3

Fig 4.20: The basic Z-match circuit showing the tapped-down feed arrangement.

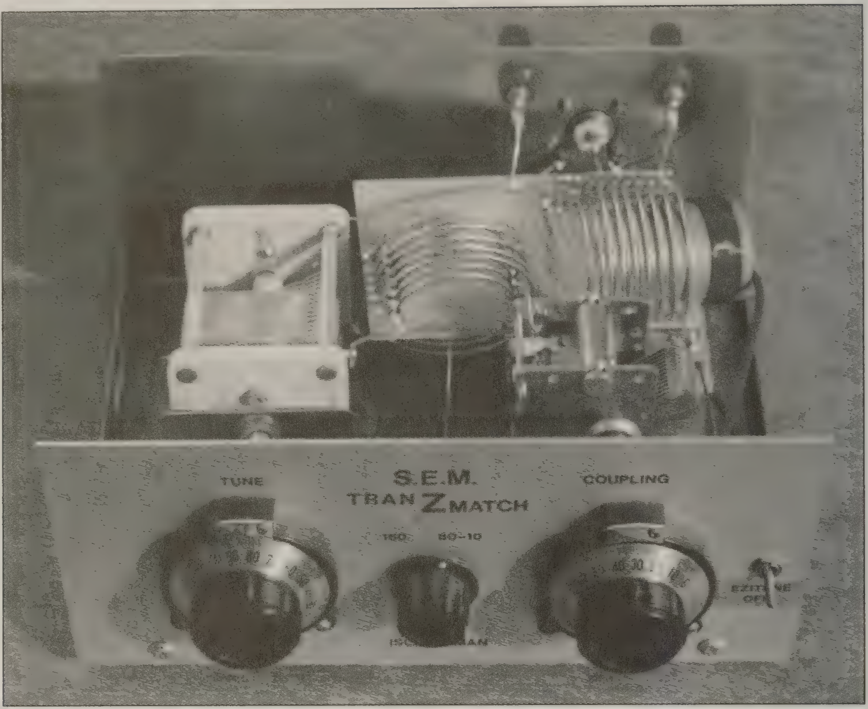


Fig 4.21: Commercial version of the Z-match, the SEM TranZmatch.

were produced commercially (for instance, the one illustrated in **Fig 4.21**) and they are described here because they are easily available and cheap.

EARTH LEAD TUNERS

In Chapter 3 the importance of a resonant counterpoise was discussed. But just like the antenna itself the one single-length radial can be tuned to place a very low RF potential at the transceiver on any band by inserting an LC series tuning circuit between the transmitter and the radial.

Such a units are commercially available. The MFJ 931 is an example of one of these and is described as an Artificial Ground as shown in **Fig 4.22**. These

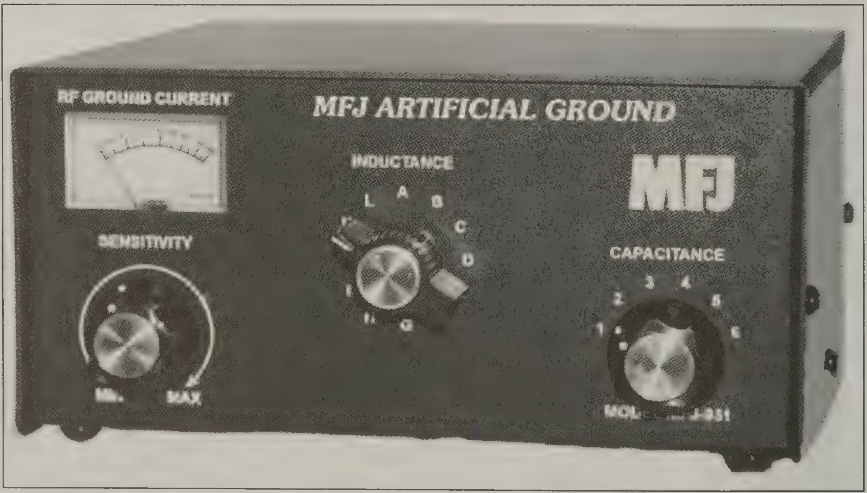


Fig 4.22: The MFJ-931 radial tuner - also known as an artificial ground. [Photo courtesy of Waters &Stanton plc]

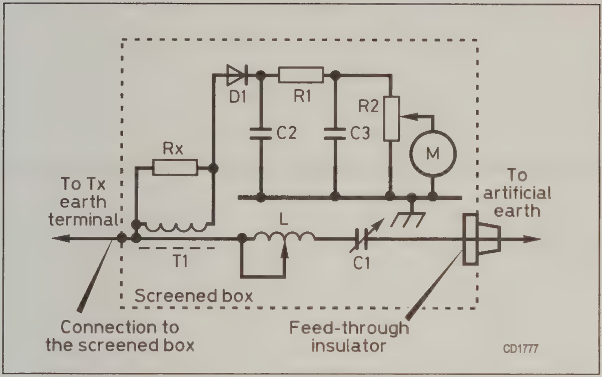


Fig 4.23: SM6AQR's earth lead tuner. T1 = Amidon T-50-43 ferrite toroid; the primary is simply the earth lead through the toroid centre; secondary = 20 turns small gauge enamelled wire. L = 28µH rollercoaster or multi-tapped coil with 10-position switch; see text. C1 = 200pF or more air variable, >1mm spacing, insulated from panel and case. C2, C3 = l0nF ceramic. DI = AA119; R1 = 1kΩ; R2 = 10kΩ pot, Rx see text. M = 100µA or less.

units, which have in addition to the LC circuit, a through-current RF indicator which helps tuning the radial or earth lead to resonance (maximum current).

SM6AQR designed the earth lead tuner shown in **Fig 4.23.** It uses a 200 - 300pF air spaced tuning capacitor with a spacing of at least 1mm; the capacitor and its shaft must be insulated from the tuner cabinet. The inductor is a 28µH roller coaster. Alternatively, a multi-tapped fixed coil plus with as many taps as possible could be used. The use of multi-tapped coil in place of a roller coaster is described earlier in this chapter.

The tuning indicator consists of a current transformer, rectifier, smoothing filter, sensitivity potentiometer and DC microammeter. The 'primary' of the current transformer is the artificial earth lead itself; it simply passes through the centre of the T1 ferrite toroid, onto which a secondary of 20 turns of thin enamelled wire has been wound. Rx, the resistor across the T1 secondary, should be non-inductive and between. 22 and 1100 ohms; it is selected such that a convenient meter deflection can be set with the sensitivity control R2 on each required frequency and for the RF power used.

A separate electrical safety earth should always be used, in addition to the RF earth already described.

COMPONENTS FOR ATUs

While components for handling QRP levels of RF power can be obtained from some electronic catalogues, the same cannot be said for components for higher power. This tends to discourage building of ATUs, which is a pity because this sort of equipment is relatively simple, especially when compared with the transceivers now in use.

However, these components are available at rallies and usually come in the form of an ex-military or commercial unit.

REFERENCES

[1] 'Save your tuner for two pence', Tony Preedy, G3LNP, *Radcom* April 1995.

[2] 'PicATUne - the intelligent ATU', Peter Rhodes, G3XJP, *RadCom* September 2001 - January 2002.

[3] 'A General-Purpose Antenna Tuning Unit', Mike J Grierson, G3TSO. *RadCom*, January 1987

5

Fixed beam antennas

Many HF operators use rotatable antennas to achieve gain and directivity in a prescribed direction, and these antennas are described in later chapters. However, it is sometimes easier and cheaper to install a fixed directional antenna which can be mono- or bi-directional, or can be remotely switched to obtain maximum gain (or a receive null) in the desired direction.

PHASED VERTICAL BEAM ANTENNAS

A phased array is a set of similar (usually identical) vertical antennas arranged in a regular geometric way and fed with a specific set of RF sources having a defined relationship to each other in terms of current magnitude and phase. Phased arrays offer a way of achieving modest gain and good reception directivity from a low profile antenna. Gains of up to 6dB, with front to back ratios of 20dB, can be achieved relative to a single vertical element with a well-designed phased vertical array.

A practical phased array system will consist of the set of radiators, earth systems, feedlines, networks to shift phase and match impedances and a switch box. This box contains relays that switch the feedlines and allows the beam headings to be changed by changing the current distribution amongst the elements in the array. In some cases phasing and impedance matching is achieved by feeding the antennas via specific lengths of coaxial cable. Other methods use inductors or capacitors in addition to the coax feeds.

Mutual coupling between the elements in an array changes the impedances of the elements from the impedances if the elements were in isolation. These effects can be large and will change current distribution and relative phases. The performance of an array is critically dependent on errors in currents or phase relationships

For this reason, full details of phased verticals are beyond the scope of this chapter so the

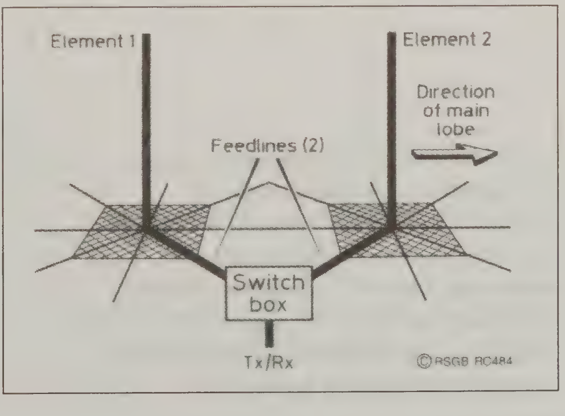


Fig 5.1: A two-element array using quarter wavelength elements spaced quarter wavelength apart. With element 1 fed at 0 degrees and element 2 fed at 90 degrees, the lobe is in line with the elements. The arrow shows the direction of maximum radiation.

following are brief descriptions, with references to detailed construction and setting up. A detailed description of the phased vertical antenna was written by G3PJT [1].

One of the simplest arrays is a pair of quarter wavelength verticals, spaced at a quarter wavelength apart and fed with RF currents which are equal but 90 degrees out of phase. The array shown in **Fig 5.1** has a gain of 3dB over a single vertical. It produces a cardioid pattern having a front-to-back ratio of 20dB with a front-to-side of about 3dB. With element 1 fed at 0 degrees and element 2 fed at 90 degrees the lobe is in line with the elements, and the arrow shows the direction of maximum radiation.

More common is the 4-element array shown in **Fig 5.2**. This arrangement uses four quarter wave radiators, arranged in a quarter wavelength-square, the so called '4-Square' array. This has gain of up to 6dB with a front-to-back ratio of 20dB with a front-to-side of 10-15dB.

The elements are fed with equal currents in the following phase relationship.

Element 1	0 degrees
Element 2	90 degrees
Element 3,	180 degrees
Element 4	-90 degrees

The array fires diagonally across the square in the direction of element 3, from element 1 to 3 as shown in **Fig 5.2**.

The disadvantage of the quarter wave 4-square is that it needs quite a bit of space. However there is nothing sacred about the quarter wave spacing. For example, providing that the current phase relationships are changed, satisfactory patterns can be obtained for spacings between 2.5 and 15m, corresponding to spacings of 1/16 to 3/8 wavelengths at 7MHz. The optimum phase difference lying between 160 and 80 degrees respectively (for equal current amplitude).

G3HCT has developed an array for 7MHz using three elements, which are spaced only 1/8 wavelength (5.32m) apart [2]. This antenna system is capable of switching the beam in any one of six directions.

The disadvantage of closer spaced arrays is that they are more critical to set up, requiring accurate measurements of impedance. The 4-square can be

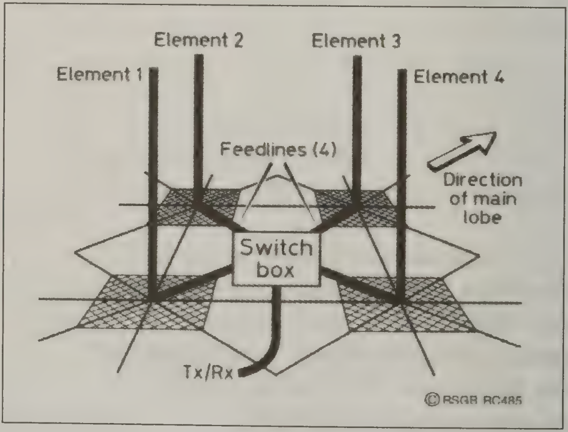


Fig 5.2: the '4-Square' array uses four quarter wave radiators, arranged in a quarter wavelength-square. The elements are fed with equal currents in the following phase relationship; Element 1, 0 degrees; Element 2, 90 degrees; Element 3, 180 degrees, Element 4, -90 degrees. The array fires diagonally across the square, indicated by the arrow.

set up using measurements of RF current and phase using simple test equipment.

The performance of a phased array can more easily achieved if all the elements in the array are identical in length of element, earth system and feed impedance. Making a good earth system was described earlier in this chapter. Further details of the phased vertical design and construction can be found at [3], [4] and [5].

FIXED LONG WIRE BEAM ANTENNAS

Occasionally a high gain fixed direction antenna can be useful for certain experimental work. An example of this was when the Narrow Band Television Association transmitted 40 line, mechanical scan, television pictures from Amberley museum in Sussex across the Atlantic to the USA in 2003. This was done to commemorate the Baird transmission on 8 and 9 February 1928. A fairly high ERP was required to ensure the TV signals would get through so a high gain antenna was required.

The antenna used was a V-beam. This antenna provides a combination of low cost, good gain bandwidth product, electrical and mechanical simplicity and ease of design and construction. The downside is that a fixed wire beams need a lot of space.

V-beams

The V-beam consists of two wires made in the form of a V and fed at the apex with twin wire feeder, as shown in **Fig 5.3**. A long-wire antenna, two wavelengths long and fed at the end, has four lobes of maximum radiation at an angle of 36 degrees to the wire. If two such antennas are erected horizontally in the form of a V with an included angle of 72 degrees, and if the phasing between them is correct, lobes 1, 2, 3 and 4 to add in the direction of the bisector of the apex.

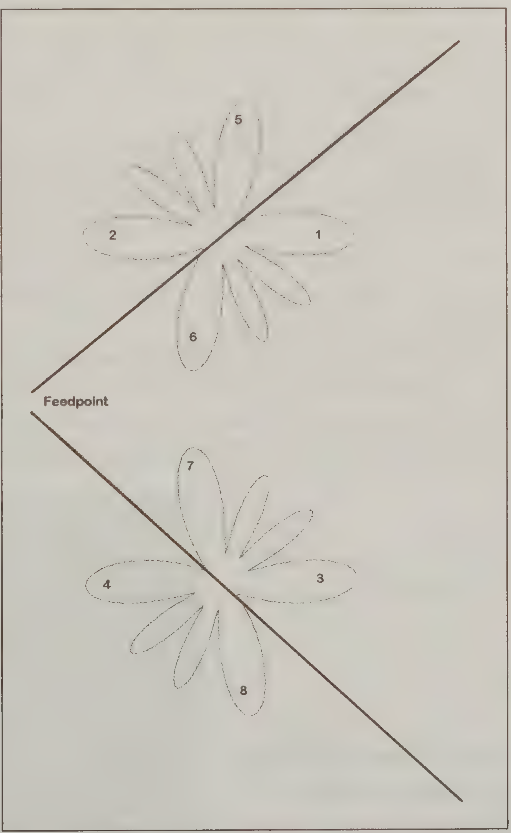
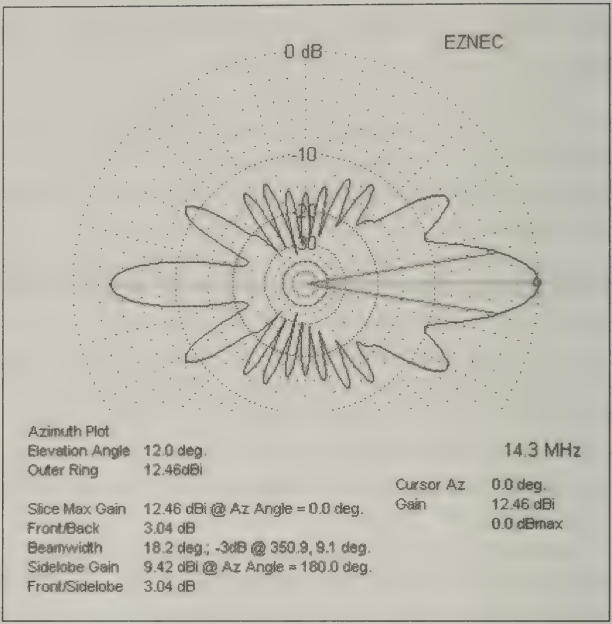


Fig 5.3: The azimuth polar diagrams of two wires, two wavelengths long, arranged in a V-beam configuration. Lobes 1, 2, 3 and 4 add in the direction of the bisector of the apex. All other lobes tend to cancel.



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Azimuth Plot
Elevation Angle   12.0 deg.
Outer Ring        12.46dBi
                                                    Cursor Az    0.0 deg.
Slice Max Gain    12.46 dBi @ Az Angle = 0.0 deg.   Gain         12.46 dBi
Front/Back        3.04 dB                                        0.0 dBmax
Beamwidth         18.2 deg.; -3dB @ 350.9, 9.1 deg.
Sidelobe Gain     9.42 dBi @ Az Angle = 180.0 deg.
Front/Sidelobe    3.04 dB
```

Fig 5.4: Prediction of the performance of the V-beam used by the Narrow Band Television Association (see text) using EZNEC4. The antenna is bi-directional because it is not terminated.

All other lobes tend to cancel. The result is a pronounced bi-directional beam as shown in **Fig 5.4**.

The directivity and gain of V-beams depend on the length of the legs and the angle at the apex of the V. This is likely to be the limiting factor in most amateur installations, and this is the first point to be considered in designing a V-beam. The correct angle and the gain to be expected in the most favourable direction is given in **Table 5.1**.

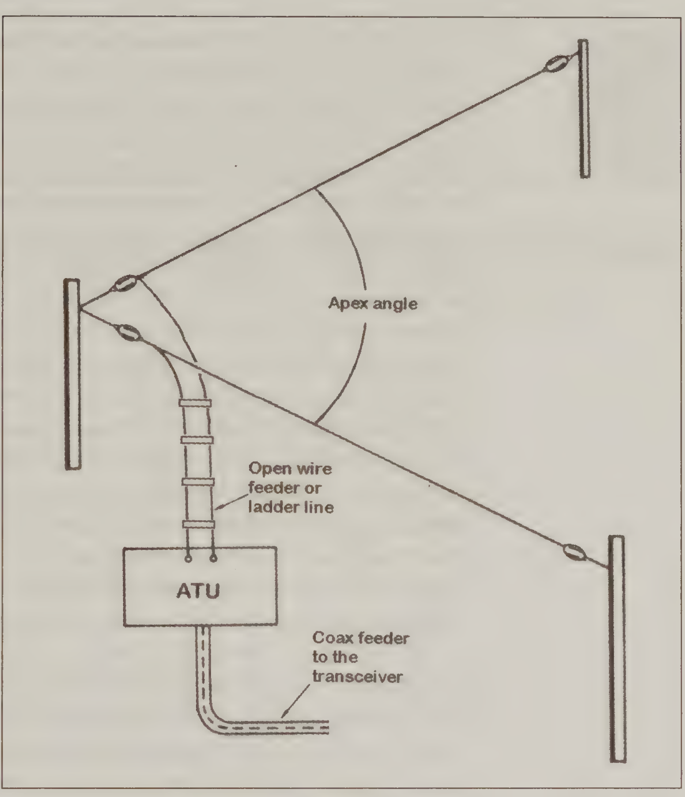
A practical V-beam capable of producing bi-directional high gain on the higher frequency bands (14 to 29MHz) is shown in **Fig 5.5**. V-beams are often constructed so that the apex is placed as high as possible with the ends close to the ground. This arrangement means that only one mast is required for the installation and if space were available several V-beams pointing in different directions could use a common support.

The V-beam so far discussed is known as resonant. The input impedance of this antenna may rise to 2000 ohms in a short V but will be between 800 and 1000 ohms in a longer antenna and thus 400 to 600-ohm feed lines can be used, matched to transceiver with a suitable balanced ATU.

Leg length Wavelength	Gain Dbd	Apex Angle Degrees
1	3	108
2	4.5	70
3	5.5	57
4	6.5	47
5	7.5	43
6	8.5	37
7	9.3	34
8	10	32

Table 5.1: V-beam gain and apex angles for given lengths of element.

Fig 5.5: A practical resonant V-beam for the HF bands 14 to 29MHz. Ideally a balanced line ATU should be used to ensure an equal current level in each element.


Apex angle
Open wire feeder or ladder line
ATU
Coax feeder to the transceiver

The V-beam can be made unidirectional if it is terminated with resistors placed approximately a quarter wavelength from the ends of the elements. A suitable value of resistor would be 500 ohms for each leg. Termination resistors have the effect of absorbing lobes 2, 4, 6 and 7 in Fig 5.4 and the elements become travelling wave devices.

The Narrow Band Television Association V-beam antenna was 33m high at the apex and 3m high at the ends, with the apex being supported by a tree on top of a 33m high cliff.

The rhombic

The rhombic antenna is a V-beam with a second V added, see **Fig 5.6(a)**. The same lobe addition principle is used but there is an additional complication, because the lobes from the front and rear halves must also add in phase at the required elevation angle. This introduces an extra degree of control in the design so that considerable variation of pattern can be obtained by choosing various apex angles and heights above ground.

The rhombic antenna gives an increased gain but takes up a lot of room and requires an extra support. As with the V-beam - the resonant rhombic has a bidirectional pattern, and the terminated rhombic, shown in **Fig 5.6(b)**, an

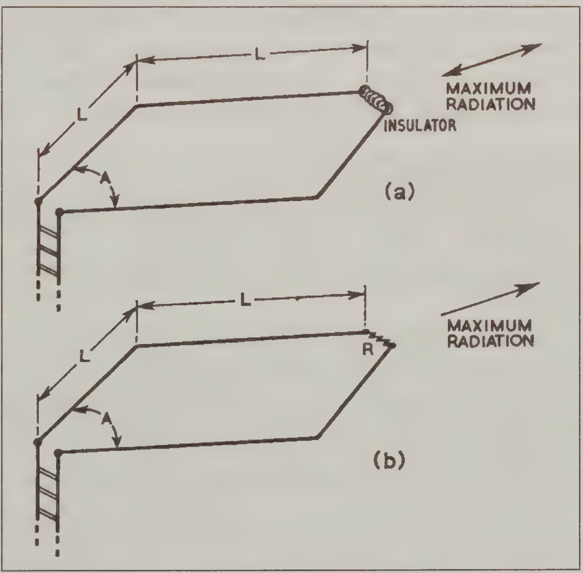


Fig 5.6: The rhombic antenna. (a) shows the resonant unterminated version, (b) the terminated version.

unidirectional one. The terminating resistance absorbs noise and interference coming from the rear direction as well as transmitter power, which would otherwise be radiated backwards. This means that it improves signal-to-noise ratio by up to 3dB without affecting signals transmitted in the wanted direction.

The use of tuned feeders enables the rhombic, like the V-beam, to be used on several amateur bands. The non-resonant rhombic differs from the resonant type in being terminated at the far end by a non-inductive resistor comparable in value with the characteristic impedance, the optimum value being influenced by energy loss through radiation as the wave travels outwards. An average termination will have a value of approximately 800 ohms. It is essential that the terminating resistor be as near a pure resistance as possible, ie without inductance or capacitance - this rules out the use of wire-wound resistors. The power rating of the terminating resistor should not be less than one-third of the mean power input to the antenna. For medium powers suitable loads can be assembled from series or parallel combinations of say, 5 ohm carbon resistors. The terminating resistor may be mounted at the extreme ends of the rhombic at the top of the supporting mast. Alternatively the resistor located near ground level and connected to the extreme ends of the rhombic via twin wire feeder.

The impedance at the feed point of a terminated rhombic is 700-800 ohms and a suitable feeder to match this can be made up of 16SWG wire spaced 300mm (12in) apart. The design of the rhombic antennas can be based on Table 5.1, considering them to be two V-beams joined at the free ends.

The design of V and rhombic antennas is quite flexible and both types will work over a 2:1 frequency range or even more, provided the legs are at least two wavelengths at the lowest frequency. For such wide-band use the angle is chosen to suit the element length at the mid-range frequency.

Generally the beamwidth and wave angle increase at the lower frequency and decrease at the upper frequency, even though the apex angle is not quite optimum over the whole range. In general, leg lengths exceeding 10 wavelengths are impractical because the beam is then too narrow.

Advantages of the rhombic over a V-beam are that it gives about 1-2dB greater gain for the same total wire length and its directional pattern is less dependent on frequency. It also requires less space and is easier to terminate. The disadvantage is that it requires four masts.

REFERENCES

[1] 'Phased Vertical LF Band Antennas', Bob Whelan, G3PJT, *RadCom* May/June, 1995.

[2] ‘Phased Arrays for 7MHz’, John Bazley, G3HCT, *RadCom* March/April 1998.

[3] *Low Band Dxing*, John Devoldere, ON4UN.

[4] *ARRL Antenna Book* (1988), pages 8-8 to 8-31, Roy Lewallen, W7EL, (also described in later editions of the *ARRL Antenna Book*).

[5] ‘Vertical Phased Arrays’, Gehrke, *Ham Radio* May, June, July, Oct, Dec 1983.

6

Yagi antennas and derivatives

The rotary beam antenna has become a standard for the upper HF amateur bands, and the best known icon of amateur radio is the three-element Yagi. It offers many advantages, such as power gain, reduction in interference from undesired directions, compactness and the ability to change the azimuth direction quickly and easily. All this is suitable for a restricted site. All the beams described in this chapter are parasitic beam antennas. The basic design is the Yagi and while a full sized 14MHz three-element monobander Yagi is often too large for a small garden it may worth considering this antenna for the higher frequency bands.

Optimum dimensioning of spacing and element lengths can only be obtained over a very narrow frequency range, and the parasitic beam will work only over a relatively restricted band of frequencies. In most cases, the bandwidth of such an array is compatible with the width of the HF amateur bands.

The compactness of a parasitic beam antenna more than outweighs the disadvantage of the critical performance. No other antenna exists that can compare, size for size, with the power gain and directional characteristics of the parasitic array.

THE TWO-ELEMENT YAGI

A two-element Yagi is shown in **Fig 6.1**. The parasitic element (Ep in the drawing) is energised by radiation from the driven element, which then re-radiates. The phase relationship between the radiated signal from the driven element and the re-radiated signal from the parasitic element causes the signal from the

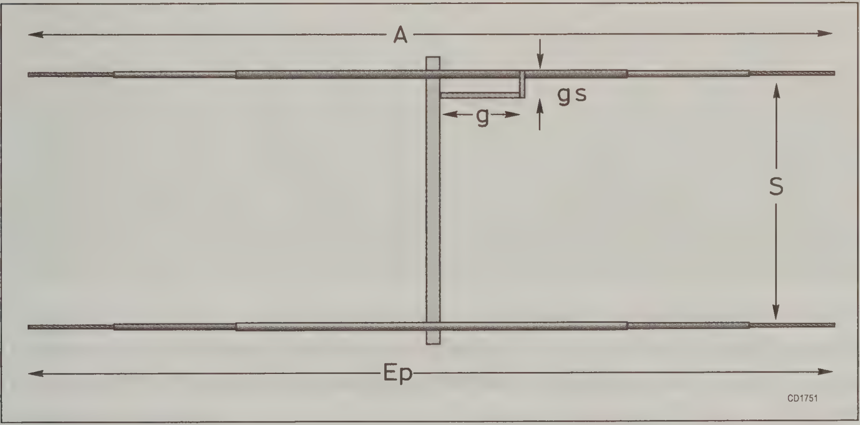
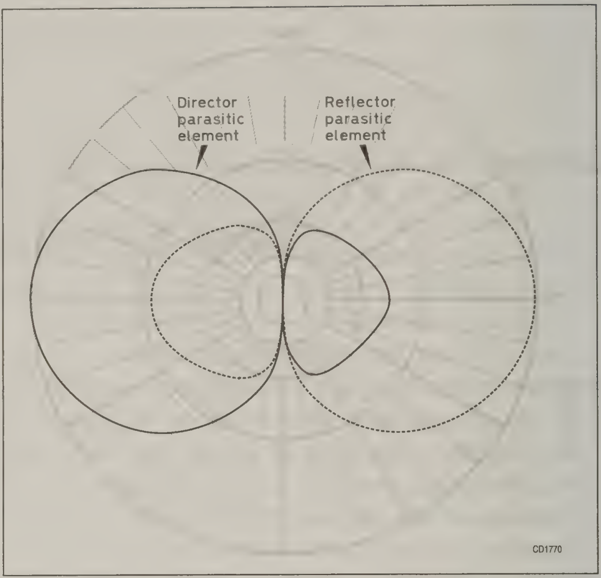


Fig: 6.1: Construction of a two-element Yagi beam with dimension references for the 20, 18, 15, 12 and 10m bands. 'g' is a Gamma match; see Chapter 11 for dimensions.

Fig: 6.2: Computer analysis of a two-element beam with the parasitic element as (a) a reflector and (b) a director



antenna to be 'beamed' either in the direction of Ep or away from it, depending on the length of the parasitic element.

This phase relationship is effected by the length of the parasitic element. When the parasitic element is longer than the driven element it operates as a reflector and causes the power gain in a direction away from Ep. When the parasitic element is shorter it operates as a director causing the power gain in a direction towards Ep.

When the parasitic element is to be used as a director, optimum spacing between it and the driven element is around 0.1 wavelength. Optimum spacing when using the parasitic element as a reflector case is approximately 0.13 wavelength

The effect of these options can be seen in the computer simulation shown in **Fig 6.2**. There is very little difference in performance with a two-element beam when the parasitic element is used either as a director or reflector, with perhaps just a marginal improvement in the front-to-back ratio when the parasitic element is a director. Additionally, a two-element beam with a parasitic director will be slightly smaller and lighter of the two options. Practical dimensions for this option are shown in **Table 6.1**.

These dimensions have been calculated using EZNEC for a non-critical design to give a free-space gain better than 6dBi and a front-to-back ratio

Frequency MHz	14.1	18.1	21.2	24.9	28.5
(S) Element Spacing (m)	2.11	1.66	1.41	1.20	1.05
(Ep) Director length (m)	9.66	7.58	6.47	5.50	4.81
(A) Driven Elt (m)	10.30	8.08	6.90	5.88	5.13
(S) Element Spacing (in)	83	65	56	47	41
(Ep) Director length (in)	380	298	255	217	189
(A) Driven Elt (in)	406	318	272	231	202

Table 6.1: Dimensions for a two-element beam. Refer to Fig 6.1 for dimensions S, Ep and A. These dimensions have been calculated using EZNEC for a non-critical design to give a free-space gain better than 6dBi and a front-to-back ratio greater than 14dB.

greater than 14dB as shown in the director parasitic element polar diagram shown in Fig 6.2. These calculations assume an average tube diameter of 20mm (0.75in) on 21MHz, which is scaled to an average of 30mm on 14MHz and 15mm on 28MHz. In practice the diameter of the tube is not critical and the diameter should be such that the antenna is mechanically stable. The elements should be made of, say, five sections that telescope into each other as shown in Fig 6.1. Aluminium scaffolding pole 50mm (2in) in diameter is useful material for the boom for any of the bands. The construction of the elements and methods of fixing the boom to the mast are described in Chapter 9.

As with all parasitic beams the dimensions of the parasitic elements determine their performance. The length of the driven element is less critical and its length only determines the feed impedance.

The feedpoint impedance of this antenna is approximately 30 ohms. To use it with 50-ohm coaxial cable a matching arrangement is necessary. The gamma match is one of the simplest to implement and the method is shown at the end of Chapter 11.

THE THREE-ELEMENT HF YAGI

By adding both a reflector and a director to a driven element, to form a three-element parasitic beam, the free-space gain is increased to over 8dBi and a front-to-back (F/B) ratio greater than 20dB, although this depends if the antenna is tuned for maximum gain or maximum front-to-back ratio. I tend to tune beam antennas for maximum F/B ratio. The reason for this approach is that adjustments to the F/B ratio make a marked difference that is easy to measure. For example the polar diagram of the W3SAI antenna [1] shown in **Fig 6.3** has a gain of 8.54db and the front-to-back is only 14.65dB.

On the other hand, the polar diagram of an antenna selected for a good front-to-back ratio (23.4dB), such as the one shown in **Fig 6.4**, is only 0.4dB down in

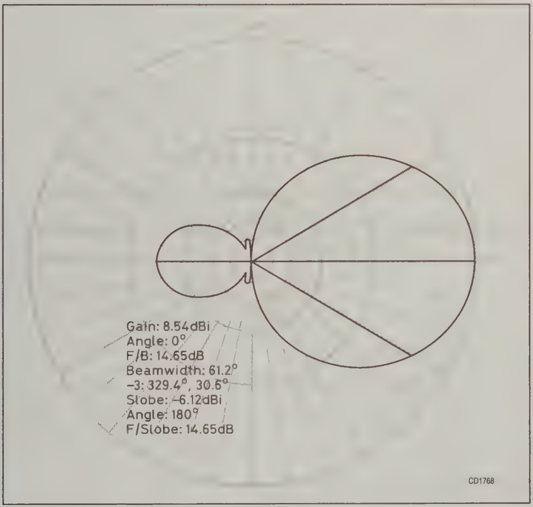


Fig 6.3: A three-element beam from the *W3SAI Beam Antenna Book* shows high gain and a F/B ratio of nearly 15dB.

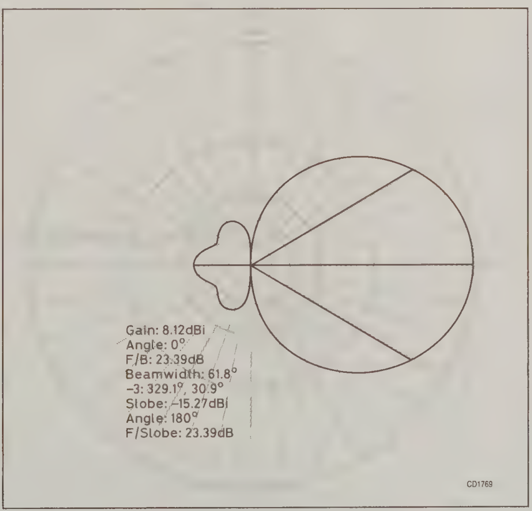


Fig 6.4: Polar diagram of a three-element beam designed using EZNEC for a high F/B ratio at the expense of gain.

Frequency MHz	14.1	18.1	21.2	24.9	28.5
(S) Element Spacing (m)	2.96	2.32	1.98	1.67	1.47
(D) Director length (m)	9.66	7.60	6.47	5.52	4.83
(A) Driven Elt (m)	10.30	7.92	6.76	5.76.	5.03
(R) Reflector length (m)	9.66	8.24	6.49	5.99	5.23
(S) Element Spacing (in)	116	91	77	66	58
(D) Director length (in)	382	229	254	216	190
(A) Driven Elt (in)	402	314	268	229	200
(R) Reflector length (in)	414	324	276	236	206

Table 6.2: Dimensions for a three-element beam. Refer to Fig 6.5 for dimensions S, D, R and A. The dimensions are shown in metres and inches and have been calculated using EZNEC for a non-critical design to give a free-space gain better than 8dBi and a front-to-back ratio greater than 20dB.

forward gain on the W3SAI antenna. As 6dB = 1 'S' point the improvement of 1.5 'S' units on F/B is noticeable. The gain difference of 0.42dB is not going to be noticed on any 'S' meter.

The construction is similar to that described for the two-element beam. The dimensions for this antenna are given in **Table 6.2** and are read in conjunction with **Fig 6.5**. A typical three-element beam, made from 'junk' aluminium tubing (see Chapter 8), is shown in **Fig 6.6**.

The feedpoint impedance of this antenna is around 25 ohms. To match it to 50-ohm coaxial cable a matching arrangement is necessary, which is described in Chapter 11.

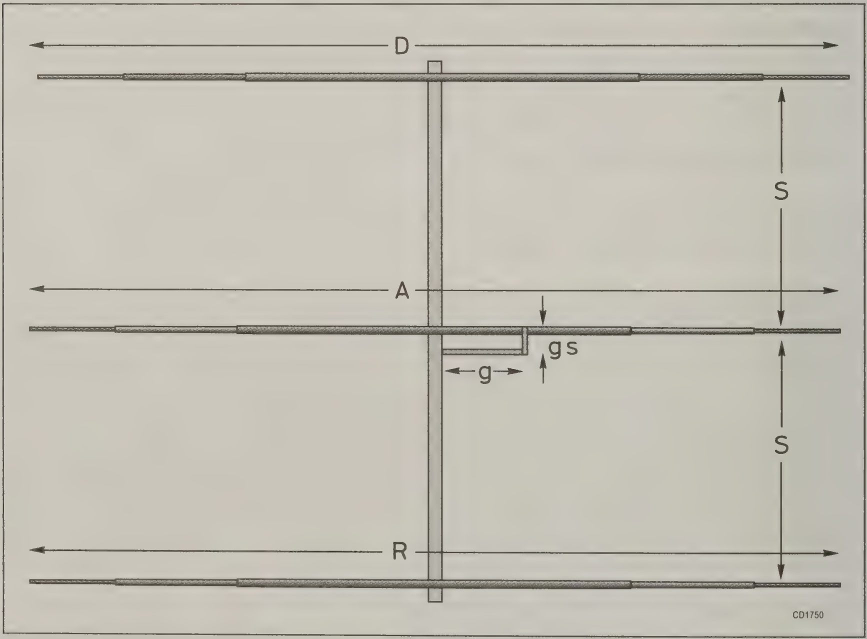


Fig 6.5: Construction of a three-element beam with dimension references for the 20, 18. 15, 12 and 10m bands. 'g' is a Gamma match; see Chapter 11 for dimensions.

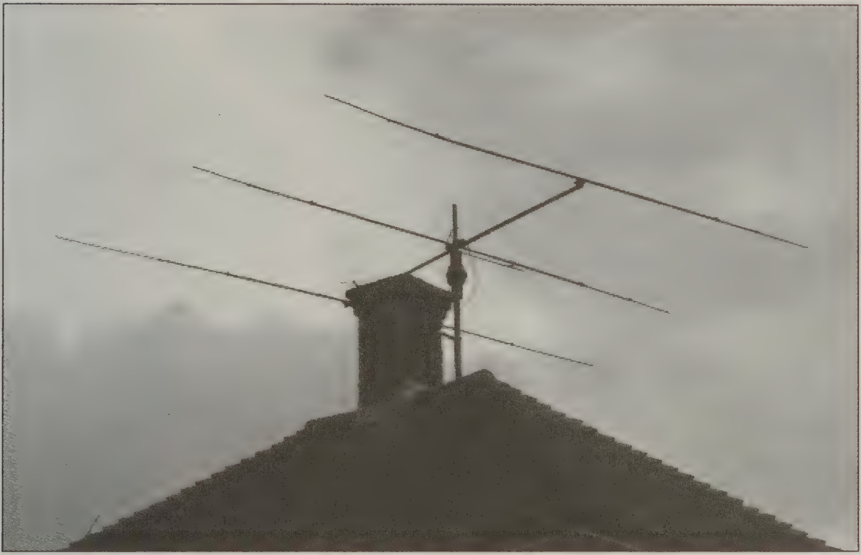


Fig 6.6: A three-element Yagi beam for 10m can be accommodated on the roof of a relatively small house.

HF BEAMS WITH BENT ELEMENTS

The 10 metre (33ft) 'wingspan' of a conventional Yagi for 20m can be a problem for many locations. So can the elements be bent, as is done with a dipole when trying to fit it into a smaller space, and still retain the beam characteristics?

A configuration, where the elements of a two-element beam were bent so that the 'wingspan' was halved, was was first suggested by John Reinartz, W1QP, way back in October 1937. Burton Simpson, W8CPC, constructed such an antenna [2], the elements of which were supported on a wooden frame. This allowed the element ends to be folded towards each other. The 14MHz antenna was constructed from 1/4in copper tubing with brass tuning rods that fitted snugly into the ends of the elements for tuning.

A wire edition of the W1QP/W8CPC two-element antenna was described in 1973 by VK2ABQ [3]. In this configuration, the tips of the parasitic and driven elements support each other in the horizontal plane. The insulators are constructed so that the tips of the elements are 6mm (1/4in) apart. According to the VK2ABQ, this capacitive end couples the reflector from the driven element although the gap between the tips of the elements is described as 'not critical'.

The computer model of the W1QP/W8CPC/VK2ABQ arrangement suggests that the driven element/parasitic element coupling is the same as for a wide-spaced two-element Yagi. Its performance is shown in **Fig 6.7**.

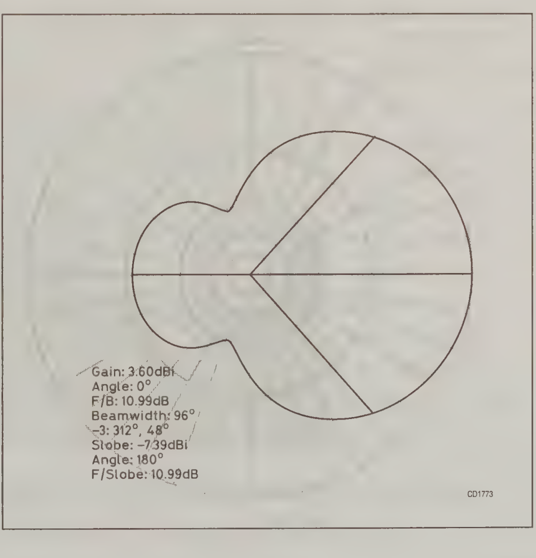


Fig 6.7: Computer analysis of a W1QP/W8CPC/VK2ABQ configuration

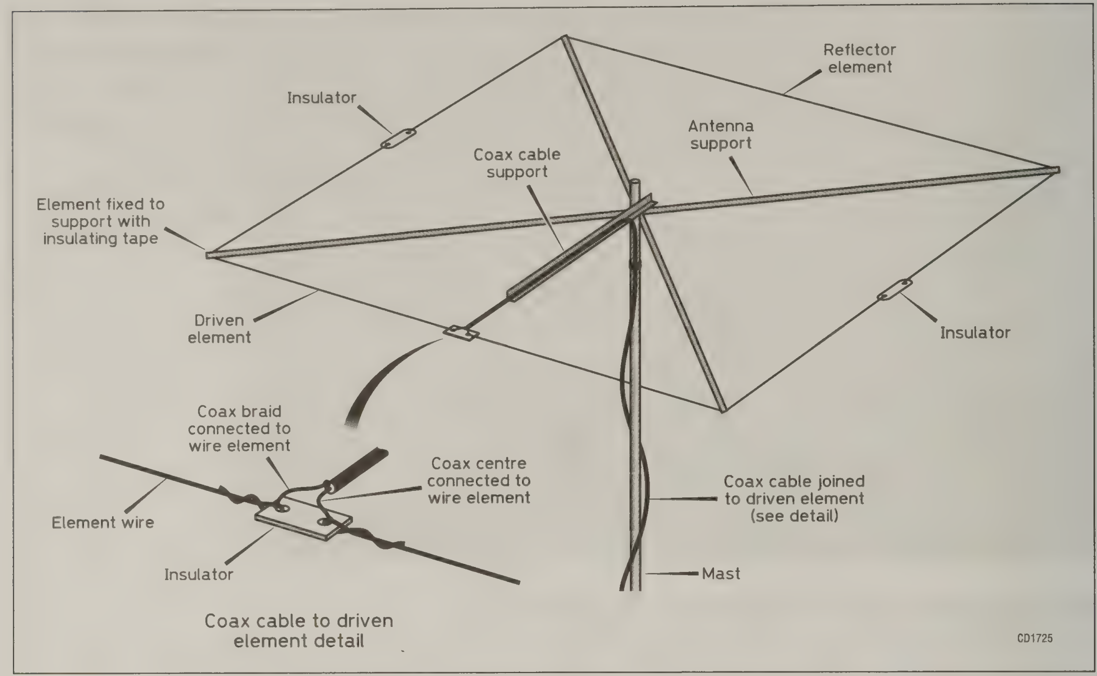

Reflector element
Insulator
Antenna support
Coax cable support
Element fixed to support with insulating tape
Driven element
Insulator
Coax braid connected to wire element
Coax centre connected to wire element
Coax cable joined to driven element (see detail)
Element wire
Insulator
Mast
Coax cable to driven element detail
CD1725

Fig 6.8: Perspective view of the Moxon Rectangle showing the general construction. The element supports can be made from fibreglass or weather treated cane. Details of fixing the supports to the mast are shown in Chapter 10.

The Moxon rectangle

Les Moxon, G6XN, did a lot of experimental work with the two-element Yagi with bent elements[4], particularly in optimising the element spacing. However, some of these structures are complex and difficult to reproduce. A simplified structure has been devised by L B Cebik, W4RNL [5], which he named the Moxon Rectangle, see **Figs 6.8 and 6.9**.

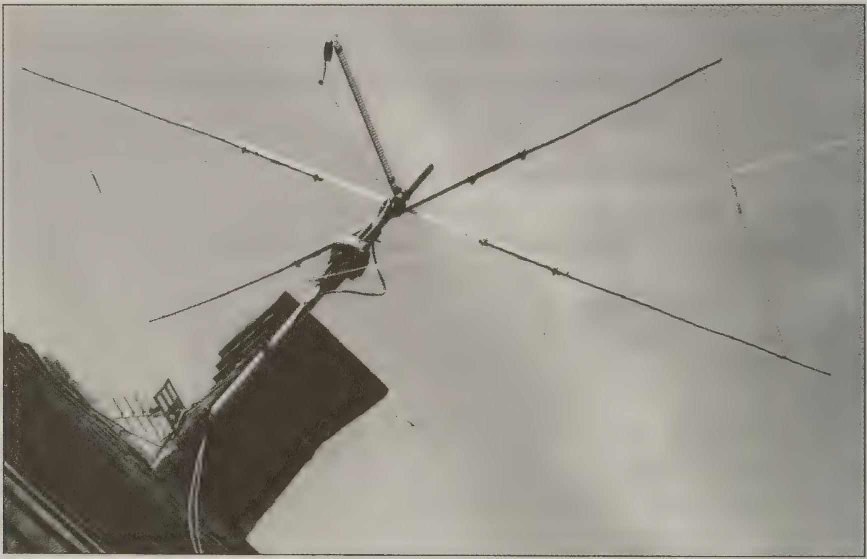


Fig 6.9: An experimental Moxon Rectangle for 21MHz using canes as element supports.

Design Frequency		Dimensions in metres (*mm)			
MHz	A	B	C	D	E
29.50	3.79	0.59	125*	0.74	1.45
24.94	4.33	0.67	140*	0.84	1.66
21.20	5.00	0.80	158*	0.99	1.95
18.12	5.96	0.94	180*	1.16	2.28
14.17	7.62	1.22	219*	1.48	3.80
10.12	10.66	1.71	305*	2.07	4.08
7.15	15.10	2.75	405*	2.93	5.73

Design Frequency		Dimensions in feet			
MHz	A	B	C	D	E
29.50	12.44	1.94	0.41	2.41	4.76
24.94	14.22	2.22	0.46	2.76	5.44
21.20	16.72	2.63	0.52	3.25	6.40
18.12	19.56	3.10	0.59	3.80	7.49
14.17	25.00	4..00	0.72	4.85	9.57
10.12	35.00	5.60	1.00	6.80	13.40
7.15	49.56	9.01	1.33	9.63	18.97

Table 6.3: Dimensions for the W4RNL designed Moxon Rectangle beam for the parameters A, B, C and D given in Fig 6.10. These dimensions have been calculated using EZNEC for a non-critical design to give a free-space gain around 5.8dBi and a front-to-back ratio greater than 30dB for a single band antenna. The elements are constructed from 1.6mm diameter copper wire.

The remarkable characteristic of this arrangement is its very high front-to-back ratio. It also has a feed impedance is close to 50Ω. The dimensions for the Moxon rectangle for 40 to 10 metres are given in **Table 6.3**. The dimensions are not perfect scaling because the length-to-wire-diameter ratio changes for each band.

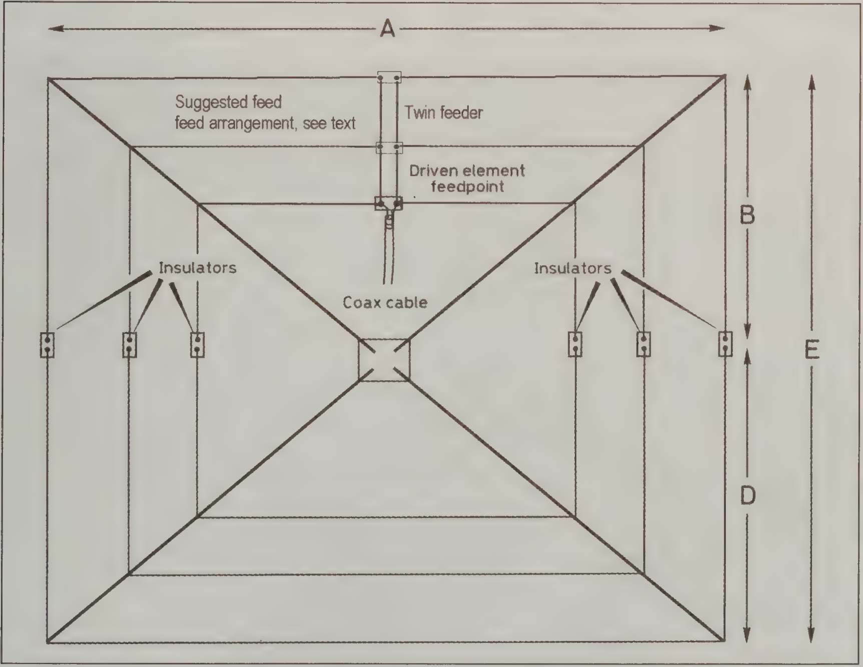


Fig 6.10: The Moxon Rectangle with dimension to be read with Table 6.3. The dimensions have been calculated for a single band antenna. For a multiband arrangement shown the lengths of the driven element may have to be adjusted to compensate for the multiband feed line.

The antenna has a feedpoint impedance between about 56 and 58 ohms, a close match to the standard amateur 50-ohm coaxial cable. Free space gain and front-to-back ratio are consistent for all the models, averaging 5.8dBi and greater than 30dB in free space, respectively.

The Moxon Rectangle can be made into a multi-band antenna by interlacing the elements for the different bands on to a common support structure, see **Fig 6.10**. The geometry of the support system ensures optimum spacing on all bands.

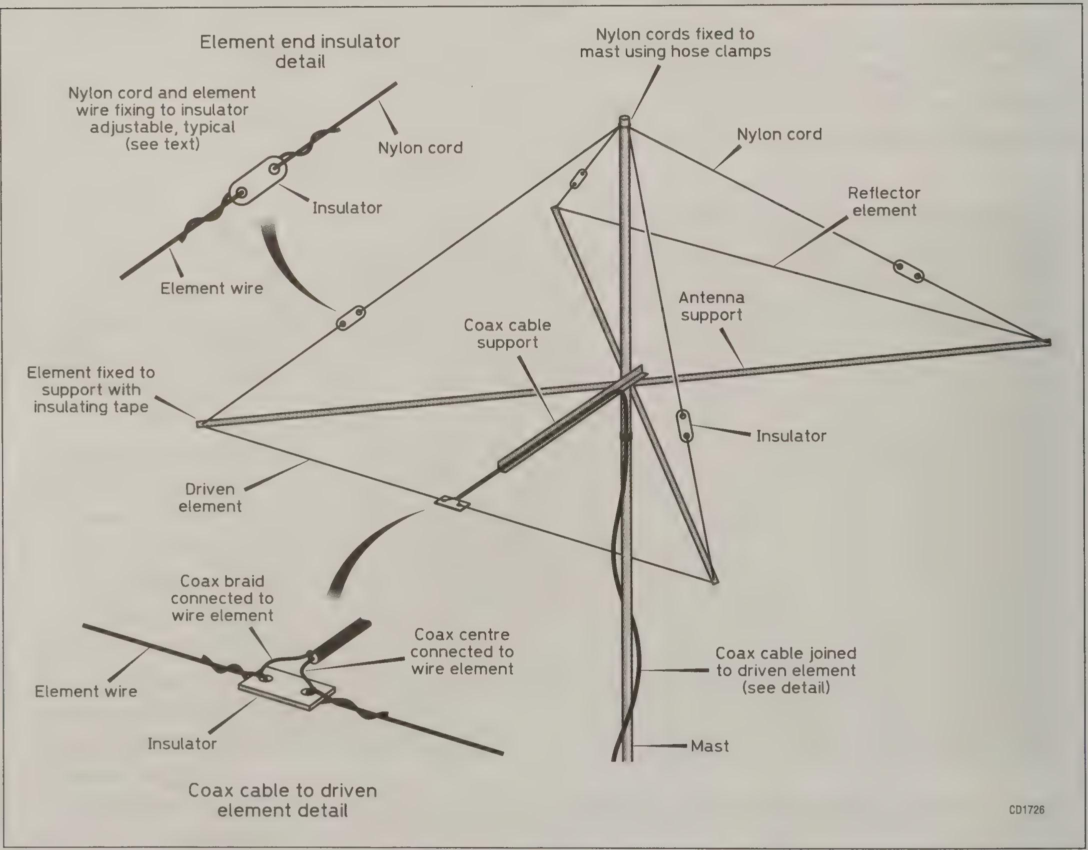
The dimensions have been calculated for a single band antenna. For a multiband antenna the lengths of the driven element may have to be adjusted to compensate for the multiband feed line arrangement.

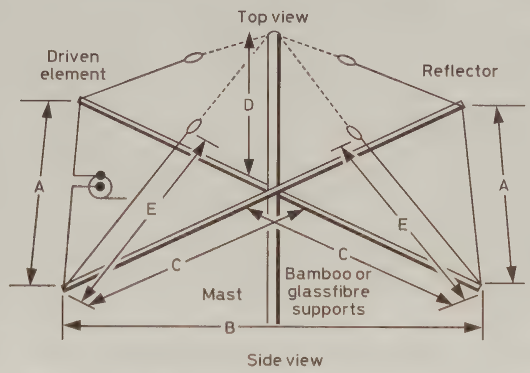
The Double D antenna

If you want to make the bent element Yagi even smaller the ends of the elements can be folded back towards the mast in the vertical plane to accommodate the length of the element in a smaller area. This results in a pyramid configuration, which I have christened the "Double-D" [6, 7] and its construction is shown in **Fig 6.11**. Plastic tape can be used to fix the wire to the supports. Alternatively, fixings used in the quad antenna described in Chapter 7 may be used.

This antenna will provide a free space gain of greater than 5dBi and a front-to-back ratio better than 20dB, which is not as good as the Moxon Rectangle but

Fig 6.11: Perspective view of the Double-D antenna, showing the general construction. The element supports can be made from weather treated cane or fibreglass. Details of fixing the supports to the mast are shown in Chapter 9.


Element end insulator detail
Nylon cord and element wire fixing to insulator adjustable, typical (see text)
Nylon cord
Insulator
Element wire
Nylon cords fixed to mast using hose clamps
Nylon cord
Reflector element
Antenna support
Coax cable support
Element fixed to support with insulating tape
Insulator
Driven element
Coax braid connected to wire element
Coax centre connected to wire element
Element wire
Insulator
Coax cable to driven element detail
Coax cable joined to driven element (see detail)
Mast
CD1726



Design data, (length in metres)

A & B = 79·00/f (MHz)
C = 55·89/f (MHz)
D = 16·41/f (MHz)
E = 31·41/f (MHz)
Total
element length = 1417·83/f (MHz)

Fig 6.12: The wire Double D Antenna with approximate design data.

is a very compact antenna. The ends of the elements, with its 'guy' supports provide a strong lightweight structure.

Use the formula in **Fig 6.12** to obtain the approximate wire lengths. In practice it is difficult to optimise the element lengths in a formula because of the geometry of the antenna. My suggestion is to make the ends of the elements (where they connect to the insulator) variable, as shown for the dipoles in Chapter 2. Then adjust reflector for maximum F/B and the driven element for minimum SWR. If you in the mood to experiment you should be able to increase the gain and improve the SWR by reducing dimension B.

The Double-D is also amenable to multibanding. A number of these antennas, for different bands, can be nested in a similar manner to the Moxon Rectangle or the quad, with a common feed as shown with these antennas.

The Double D antenna can also be constructed using a metal boom and elements as shown in **Fig 6.13** although this is a single band antenna. The ends of the elements are made of wire, which is fixed to the ends of the metal sections

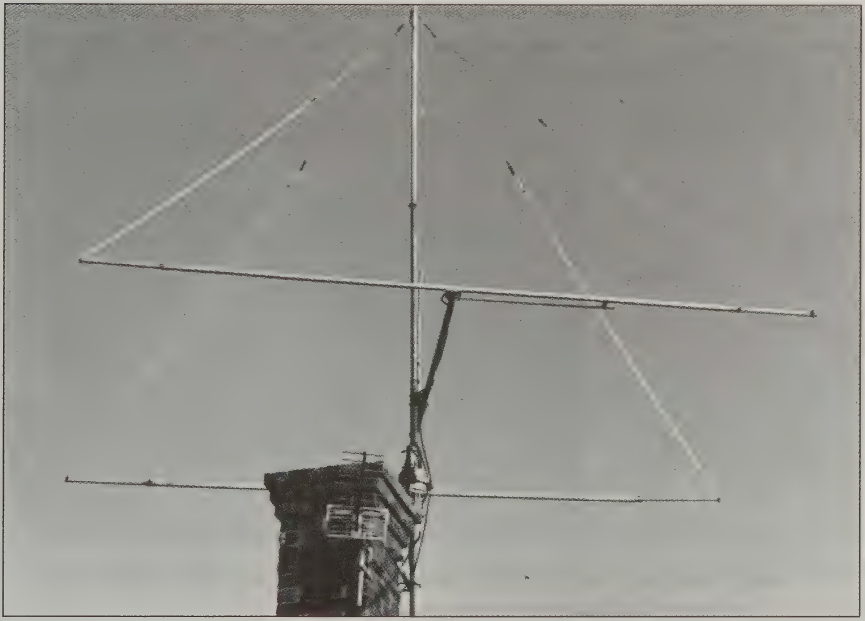


Fig 6.13: An all-metal Double D Antenna for 21MHz. This makes for a very rugged single band antenna.

using hose clamps. The data in Fig 6.12 can be used starting point for determining the overall length of the elements. Plumbers Delight construction can be used and the driven element can be gamma matched.

The HexBeam

The HexBeam is a parasitic two-element beam with the driver and reflector elements bent into a 'W' shape to conserve space, see **Fig 6.14**. It is usually constructed of wire elements strung onto a support structure of fibre-glass spreaders. A free space computer model is shown in **Fig 6.15**.

By 'bowing' the spreaders, the elements for several amateur bands can be accommodated on the same support structure and spaced apart in both the horizontal and vertical planes. This approach allows a multiband beam to be constructed with a turning radius about half that of the corresponding Yagi. The general layout of the multiband HexBeam is shown in **Fig 6.16**. Although this shows the horizontal spacing it does not show the vertical spacing, which can only be seen by studying **Fig 6.17**.

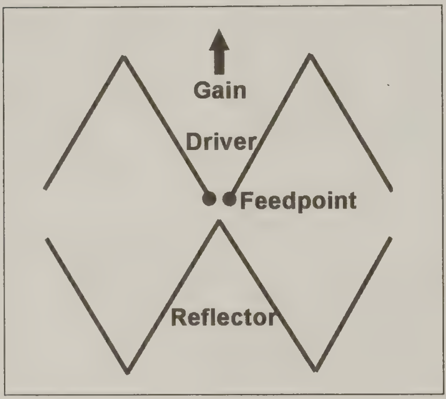


Fig 6.14: Basic configuration of a single band HexBeam.

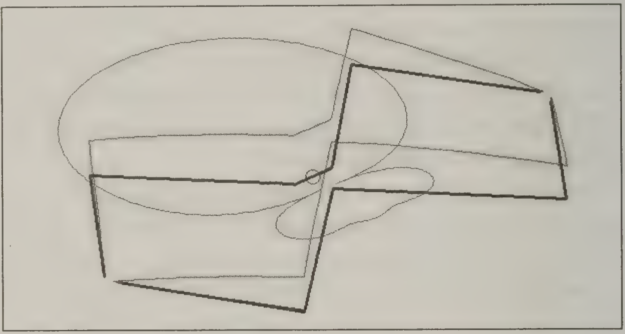
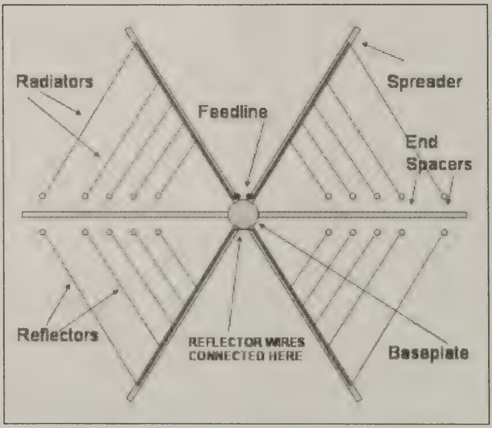


Fig 6.15: Computer model of a single band HexBeam showing the current distribution and an azimuth freespace polar diagram. The model predicts a free-space gain of 5.7dBi and a F/B of 24dB.



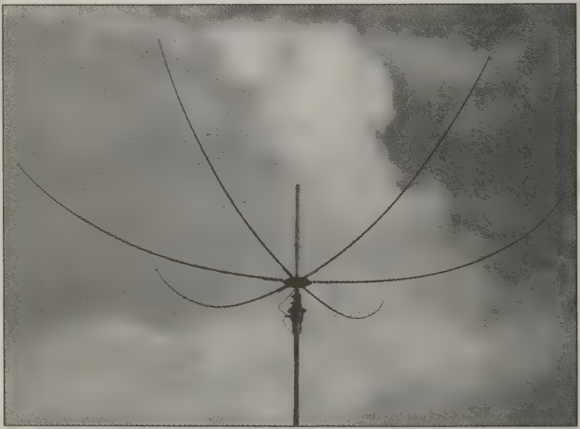


Fig 6.16 (left): Top view of a five-band HexBeam. The elements of each band are also separated vertically as can be seen in Fig 6.17 (right): A multiband HexBeam as constructed by G3TXQ.

	CW ends of bands			*SSB ends of bands*		
Band	**Freq**	**½ Driver wire length**	**½ Reflector wire length**	**Freq**	**½ Driver wire length**	**½ Reflector wire length**
20	14.050	216.0	220.5	14.200	213.6	218.0
17	18.150	166.9	170.3	18.150	166.9	170.3
15	21.100	142.8	145.7	21.300	141.4	144.2
12	24.950	121.1	123.6	24.950	121.1	123.6
10	28.100	107.7	109.9	28.600	106.2	108.4

Table 6.4: HexBeam element lengths optimised for the CW and SSB ends of the bands

G3TXQ did most of the theoretical and experimental work on this antenna and this is described in [8]. He worked with K4KIO who did most of the practical constructional design, see [9].

The main construction task is building a centre hub to support the six fibreglass element support poles. This hub must also have provision for fixing an insulated vertical support for the multiband feed system and of course provision for mounting on a mast. Several solutions are described in the web pages shown in the References. Some builders have used canes (often used in quad construction) but these don't take kindly to bowing as is required for this structure.

K4KIO specifies wire elements of 1.5mm diameter uninsulated copper and the lengths are shown in **Tables 6.4**. The dimensions are quoted in inches - to convert to the metric system multiply by 2.54 to get the equivalent in centimetres.

The method of feeding is interesting and is shown in **Fig 6.18**. 50-ohm coax is connected to the top of the HexBeam at the terminals for the 20m band. All the other bands are fed in turn through coax sections. It is important that the connections to each band are NOT inverted.

When you hear about the problems of feeding multiband quads it comes as a surprise that the method of feeding the multiband HexBeams is so simple. The practical implementation of the feed method is illustrated in **Fig 6.19**. The feedpoint height above the base plate for each band is given in **Table 6.5**.

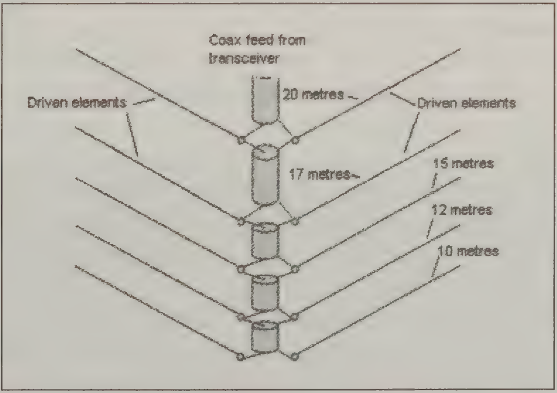
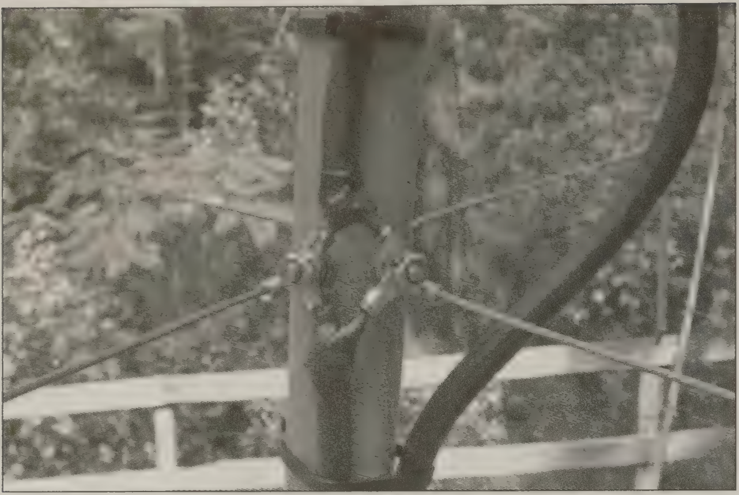


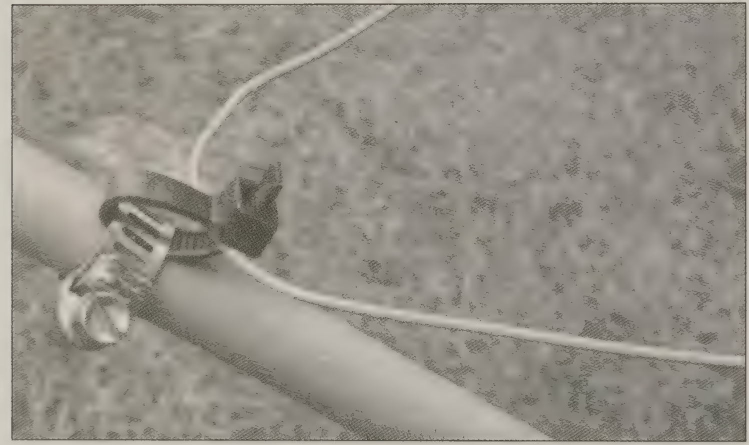
Fig 6.18: Feed line wiring configuration for a Multiband HexBeam. 50-ohm coax is connected to the top of the Hexbeam at the terminals for the 20m band.

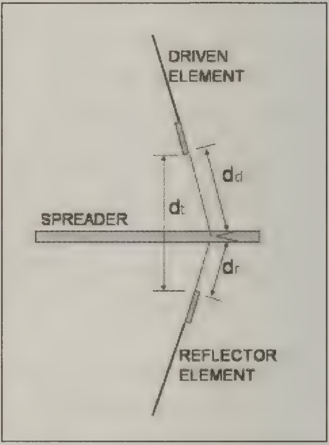


Band	F/P height inches
20m	42
17m	20
15m	14
12m	10
10m	6

Table 6.5: Distance of driven element feedpoint above the baseplate.

Fig 6.19: Feed method for the multiband HexBeam used by K4KIO.





(above) Fig 6.20: Method of fixing an uninsulated wire to the element support

(above right) Fig 6.21: Element end spacings, parameters for different bands given in Table 6.6.

Table 6.6: Element end spacing dimensions in inches.

Band	Dd	Dr	Dt
20	7.7	5.0	11.0
17	6.1	4.0	8.8
15	5.4	3.6	7.8
12	5.4	3.6	7.8
10	5.6	3.6	7.9

A suitable method of providing an insulating fixing for an uninsulated wire element to a support is shown in **Fig 6.20**. This method is also used with quads, see Chapter 7. The spacing between the ends of the reflector and driven element ends are more critical when it comes to gain and front-to- back ratio performance. The data shown in **Table 6.6** and **Fig 6.21** are by K4KIO.

On the face of it, this antenna would appear to provide a solution for a beam antenna for those with restricted sites - that means most of us! The gain and F/B figures shown in the computer model in Fig 6.15 are very good although this performance is not maintained over the whole of the bands - as is the case for all compact multiband antennas.

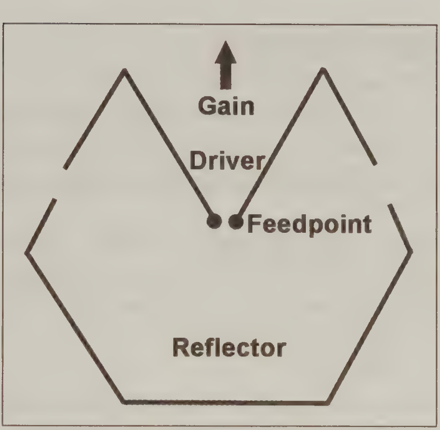


Fig 6.22: Alternative geometry of the HexBeam used by G3TXQ to improve the bandwidth gain and F/B performance.

G3TXQ has done further work on the HexBeam. He noted that a consequence of the HexBeam's geometry is a relatively narrow performance bandwidth; typically the F/B exceeds 10dB over a band equivalent to only 1.4% of the centre frequency, and the SWR is above 2:1 for a significant proportion of this band. This narrow bandwidth is largely determined by the Q of the reflector, which is about 30 for a 10m element constructed from 16SWG wire. This compares with a Q of about 10 for a linear element.

Of all the ideas evaluated by G3TXQ by far the most effective and easiest to implement was to change the shape of the reflector as shown in **Fig 6.22**. Even when using relatively thin 16SWG wire this shape has a radiation resistance of 44 ohms and a Q of about 17. It requires an increase in turning radius of about 15%. Modelling a HexBeam with this geometry produced very encouraging results with a F/B > 10dB and SWR < 2:1 across all of the 20m, 17m, 15m and 12m bands, and approximately 1MHz of the 10m band. (listening tests with DX stations indicate that the F/B could be as high as 30dB). The modelling suggested there was little to be gained by making the same change to the shape of the driver element; in fact, retaining the classic shape for the driver delivers a better match to 50 ohms and avoids a further increase in the turning radius.

A multiband version for 20m, 17m and 15m results were immediately satisfactory, but it took some time to optimise the 12m and 10m performance; the proximity of these bands often causes problematic interactions which are not always predicted by the modelling, and the final wire dimensions for these bands were a result of 'cut and try' on the testbed. (note that this is true of all parasitic antennas, particularly multiband types.)

The final dimensions of a multiband HexBeam, using 16SWG bare copper wire, is shown in **Table 6.7**. The band feedpoints are interconnected with 50ohm coax, and the array is top-fed. This five-band design requires a horizontal distance of about 130in from the centre post to the tips of the spreaders. If you are unable to accommodate this increased size, don't be tempted to stick to the classic shape for 20m and adopt the new shape for 17m to 10m: modelling shows that the 20m performance bandwidth suffers dramatically. This is probably due to the mid section of the 17m reflector providing an RF coupling path between the knees of the 20m reflector.

Band	**20m**	**17m**	**15m**	**12m**	**10m**
Driver (half-length)	218	169.5	144.5	121.7	106.8
Reflector (total)	412	321	274.4	232	204.4
End spacing	24	18.5	16	13.5	12
Vertical spacing from 10m elements	38	15	9	5	0

Table 6.7: Alternative geometry HexBeam dimensions.

REFERENCES

[1] *Beam Antenna Book*, W6SAI

[2] 'Concentrated Directional Antennas for Transmission and Reception', John Reinartz, W1QP, and Burton Simpson, W8CPC, *QST* October 1937.

[3] `'VK2ABQ Antenna', Fred Caton, VK2ABQ, *Electronics Australia*, October 1973.

[4] *HF Antennas for all Locations*, Les Moxon, G6XN (RSGB)

[5] L B Cebik, W4RNL: www.cebik.com

[6] 'Wire Beam Antennas and the Evolution of the Double-D', Peter Dodd G3LDO, *QST*, October 1984, also *Radio Communication* (RSGB) June/July 1980.

[7] *The Antenna Experimenter's Guide*, 2nd edn, Peter Dodd, G3LDO (RSGB)

[8] www.karinya.net/g3txq/hexbeam/

[9] www.leoshoemaker.com/hexbeambyk4kio/

7

The quad antenna

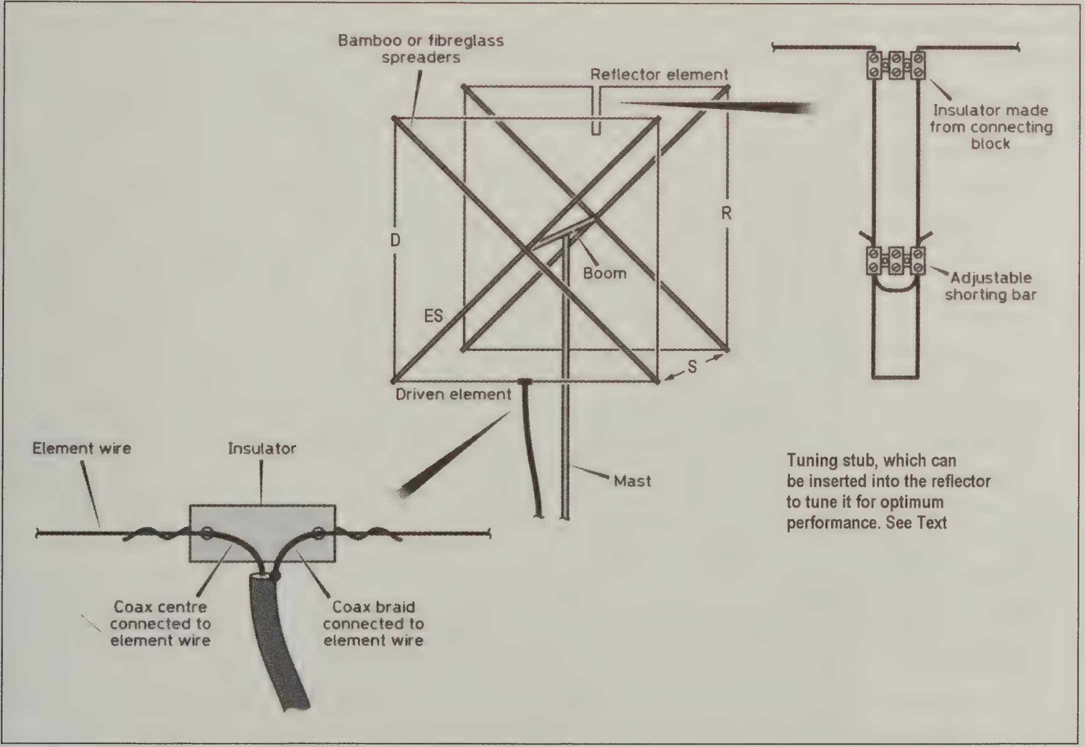
The cubical quad beam is a parasitic array whose elements consist of closed loops having a circumference of approximately one-wavelength at the design frequency. The parasitic element is normally tuned as a reflector.

It can be tuned as a director but the gain and front to back ratio is inferior. Additionally, the optimum settings are more critical.

The construction of a quad for the HF bands is shown in **Fig 7.1** and the dimensions are given in **Table 7.1**.

The reflector R can be constructed using the same dimensions as D, the driven element; a tuneable stub is then used to lower the resonant frequency of the reflector. This stub can be used to tune the reflector for the greatest front-to-back ratio of the beam. However, the lengths will have to be determined by experiment.

Fig 7.1: The construction of an HF two-element wire quad, with dimension details shown in Table 7.1.


Bamboo or fibreglass spreaders
Reflector element
Insulator made from connecting block
R
D
Boom
Adjustable shorting bar
ES
S
Driven element
Element wire
Insulator
Mast
Tuning stub, which can be inserted into the reflector to tune it for optimum performance. See Text
Coax centre connected to element wire
Coax braid connected to element wire

Frequency MHz	**14.1**	**18.1**	**21.2**	**24.9**	**28.5**
(S) Element Spacing (m)	2.98	2.34	1.99	1.70	1.49
(R) Reflector length (m)*	5.56	4.38	3.73	3.17	2.77
(ES) Element support length (m)	3.93	3.1	2.64	2.24	1.96
(D) Driven Element (m)*	5.33	4.18	3.57	3.04.	2.65
(S) Element Spacing (in)	117	92	79	67	59
(R) Reflector length (in)*	219	172	147	125	109
(ES) Element support length(in)	155	122	104	89	77
(D) Driven Element (in)*	210	164	140	120	105

**Note: These dimension are for one side of the quad only. The total length of the element is four times this figure.*

Table 7.1: Dimensions for a two-element quad beam for the upper HF bands. Refer to Fig 7.1 for dimensions D, S, R and ES. These dimensions have been calculated using EZNEC for a non-critical design to give a free-space gain around 7.5Bi and a front-to-back ratio greater than 15dB.

The dimensions given in Table 7.1 are for a quad using an element spacing of 0.14 wavelength whose computed free-space performance is shown in **Fig 7.2**. In addition the lengths of the element supports are also given. Note that the lengths of the supports could be longer than this; the length dimension is the point where the element is connected to the support.

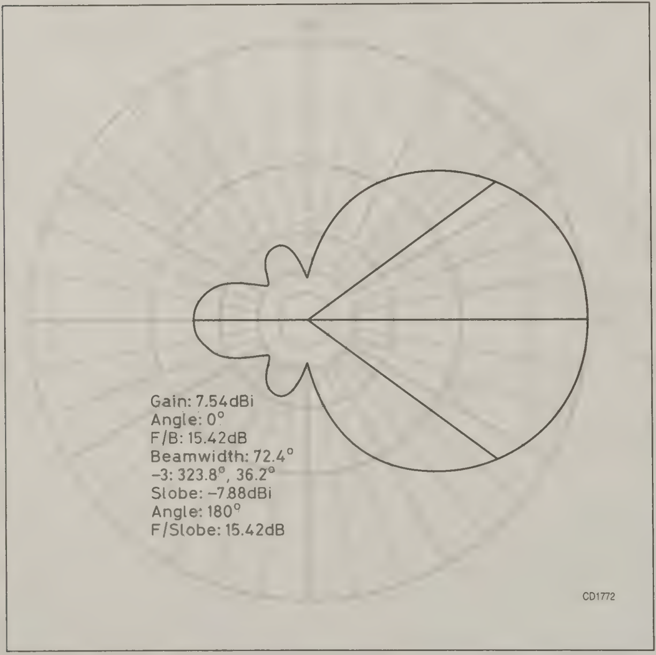


Fig 7.2: Computer analysis of a two-element wire element quad with 0.14 wavelength element spacing.

The current distribution is shown in **Fig 7.3** and shows that the maximum current occurs in the horizontal sections of the loop. The relative phases of the currents in the loop are indicated by relative positions of the current distributions to the element and that the current in the top vertical section is 180 degrees out of phase from the bottom. The polarisation of this antenna is horizontal: a driven element fed half way up one of the vertical sections would be vertically polarised.

The feed impedance of the quad using the dimensions shown in Fig 7.1 and Table 7.1, is around 65 ohms so the driven element can normally be connected directly to 50-ohm feedline with only minimal mismatch. The 0.14 wavelength spacing (S), given in Table 7.1, was chosen because it is the most prevalent in antenna literature. An example of a single band quad is shown in **Fig 7.4**. The spacing for a two-element quad can be reduced to 0.1 wavelengths without any serious deterioration in performance although the performance bandwidth will be reduced. By this I mean that the gain and directivity, together with the SWR, will be more prone to variation at the band edges. Reduced spacing lowers the feedpoint impedance and can give an improved match to 50-ohm coaxial cable.

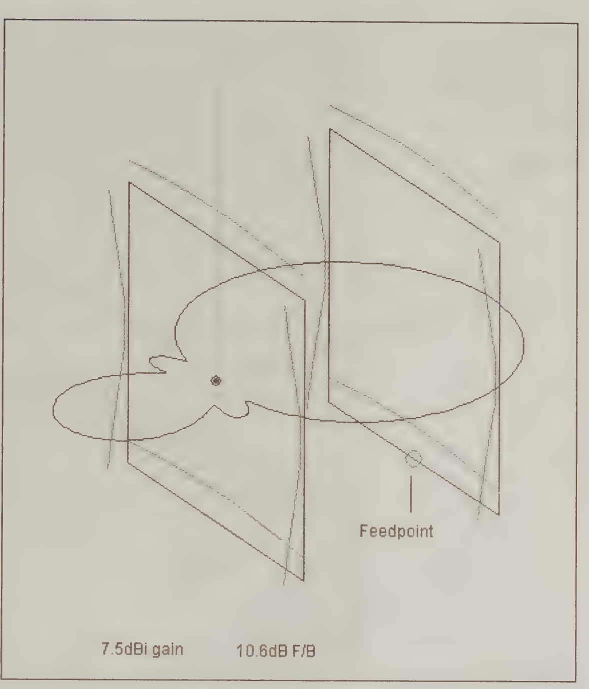


Fig 7.3: The 'View Antenna' page of an EZNEC5 analysis of a two-element wire element quad. It shows the current distribution in the elements and the signal strength directivity.

CONSTRUCTION

Element supports

Ideally, the element support spreaders should be made from tapered fibre-glass rods. These are expensive and are rather hard to come by; but they do have the outstanding advantage of being strong and durable. A much cheaper and easily obtained material is bamboo. It comes in the form of garden canes, the sort normally found in garden centres. Bamboo canes do need weather protection if they are to last more than a year or so and the favourite method is to treat them with a couple of coats of outdoor shellac or varnish. There are various wood preservatives available these days and any one of these products should prolong the life of cane spreaders. Four bamboo poles are

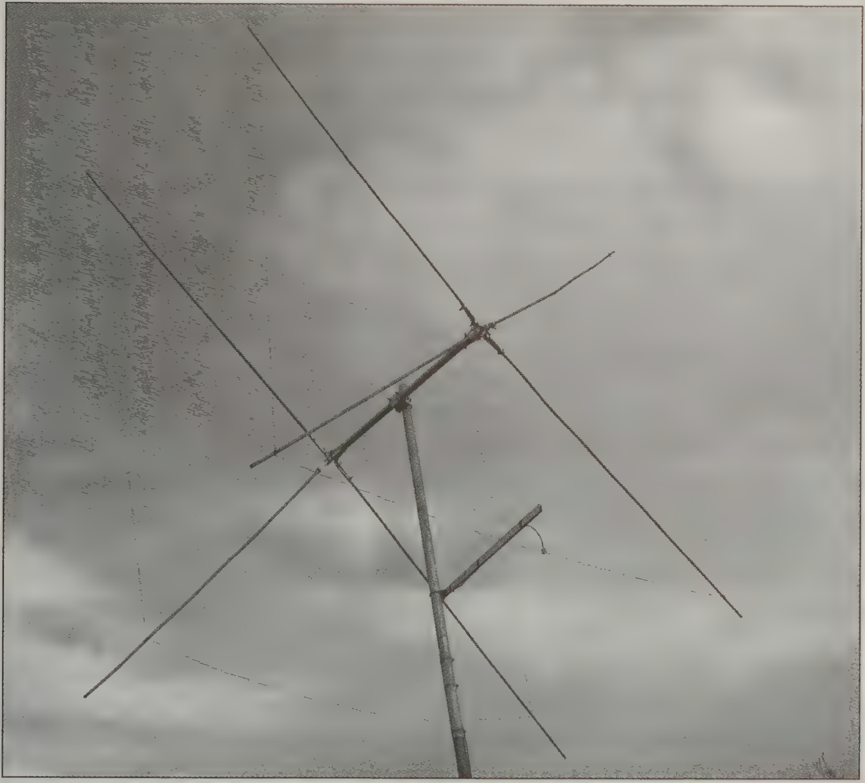


Fig 7.4: Single band quad for 28MHz. The element supports are made from bamboo canes, fixed to the boom with shelf brackets. Note the section of aluminium angle to support the coax feeder from the mast to the feedpoint.

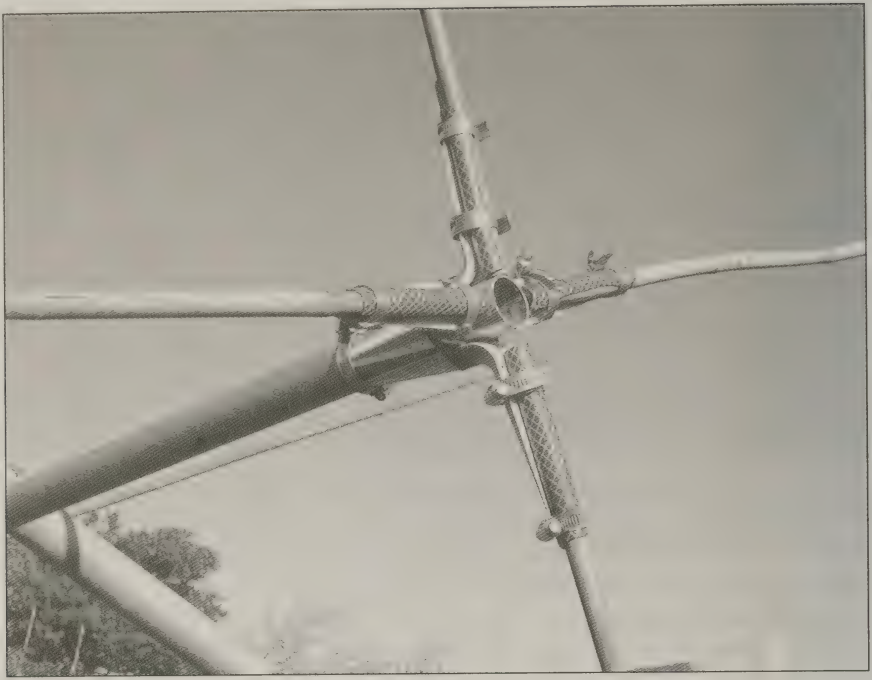


Fig 7.5: Construction of a light weight quad hub using shelf brackets.

required for each quad loop and these should be clean, straight and free of splits and cracks between the rings.

The method of fixing the element supports to the boom is often regarded as a challenge. If you want to build a really robust quad then the spider shown in Chapter 9 is recommended. It comprises two lengths of aluminium angle fixed to the boom at 90 degrees to each other, using exhaust pipe clamps. The spreaders are then fixed to the angle stock using jubilee clips in the manner described below.

There is a lightweight alternative to using the angle aluminium and U clamps and that is to use shelf brackets. These items are cheap, easy to obtain and are strong. The brackets are fixed to the boom and the spreaders fixed to the brackets using jubilee clips, or hose clamps as they call them in the USA. The main advantage of this method of construction is that you don't need any special tools other than a screwdriver. Two jubilee clips are required to fix the four shelf brackets to the boom as shown in **Fig 7.5**. This is rather a cumbersome job and more easily accomplished with two people (four hands!).

Each cane is fixed to the shelf bracket with two jubilee clips per cane. The portion of the cane clamped to the shelf bracket is encased in a short length of hose-pipe as shown in Fig 7.5; this minimises the chance of the cane splitting when the jubilee clip is tightened up. The chances are that you will not get a cane end and a piece of hose that will fit. The trick is to slice the short length of hose down one side using a Stanley knife; the hose can then be split to fit over the cane.

This quad structure with two spiders uses 20 jubilee clips. To avoid the possibility of some sort of repetitive injury that might accompany fixing all these clips, a rechargeable electric screwdriver might be in order. Almost all jubilee clips have a 7mm hex nut as well as the screwdriver slot for adjustment. For this reason it is best to use the electric screwdriver with a 7mm hex nut driver, rather than a conventional screwdriver blade.

Shelf brackets have considerable strength along the axis of the boom; after all they were designed to hold a considerable weight. The small brackets can be used to build the 28MHz quad shown in Fig 7.4 are, according to the label, capable of supporting 25kg. If you want to build a larger quad for 14MHz then larger brackets rated at 32kg would be more suitable.

Wire elements

Cut the wire elements to length as shown in Table 1. Remember to multiply the Table 1 figures by 0.95 if you are using plastic covered wire.

Insulated wire elements can be fixed to the element supports using plastic insulating tape. A better method is to fix tie wraps to the element supports using hose clamps as described in Chapter 9. This method is suitable for elements made from bare stranded copper wire and has the added advantage that the position along the along the element support is adjustable; a consideration when the element lengths are being adjusted at the tune-up phase.

Feeding the driven element

With all the quads that I have ever built the method used to connect the coax to the driven element has always been the simplest. Break the driven element in the centre of the lowest horizontal section with an insulator. Then connect the coax inner to one side of the element and the braiding to the other, as shown in the detail of Fig 7.1. As was stated earlier, the feed impedance of this quad is around 65 ohms, so the driven element can be connected directly to 50-ohm feedline with only minimal mismatch. Purists will deem this unsatisfactory because a balanced antenna is being fed with an unbalanced (coax) feeder. I have never found this to be a problem but you can quite easily fit a 1:1 current balun/choke near the feedpoint, as described in Chapter 11, if you wish.

The quad shown in Fig 7.4 uses an electrical connector block as an insulator, which provides a very convenient method of connecting the coax line to the element. Also shown in Fig 7.4 is a section of aluminium angle to support the coax feeder from the mast to the feedpoint.

MULTIBANDING THE QUAD

The quad antenna can be made into a high performance multi-band antenna, by nesting quad loops for the different bands on a common support structure as shown in **Fig 7.6**. The total area is no larger than that required by the largest beam of the group - normally a 14MHz beam for upper HF applications. The element support length (ER) should be the length for the lowest frequency band.

One of the characteristics of the multiband arrangement shown in Fig 7.6 is that the spacing between the driven element and the reflector for each band is a compromise. This does not have a great deal of effect on the directive properties of each individual band but the feed impedances may vary quite a bit with these different spacings.

One solution for obtaining optimum element spacing between the driver and the reflector in a multi-band quad is to use a structure shown in **Fig 7.7**. It comprises a boom that is only 600mm (24in) long with the boom/element supports

Fig 7.6: General view of a three-band variant of the quad using a conventional support structure.

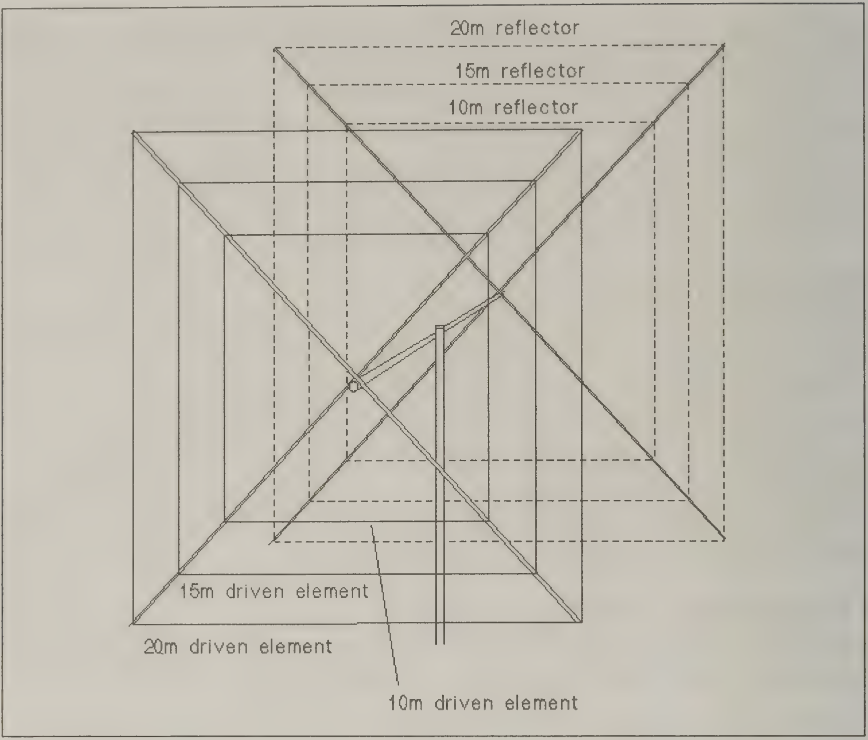
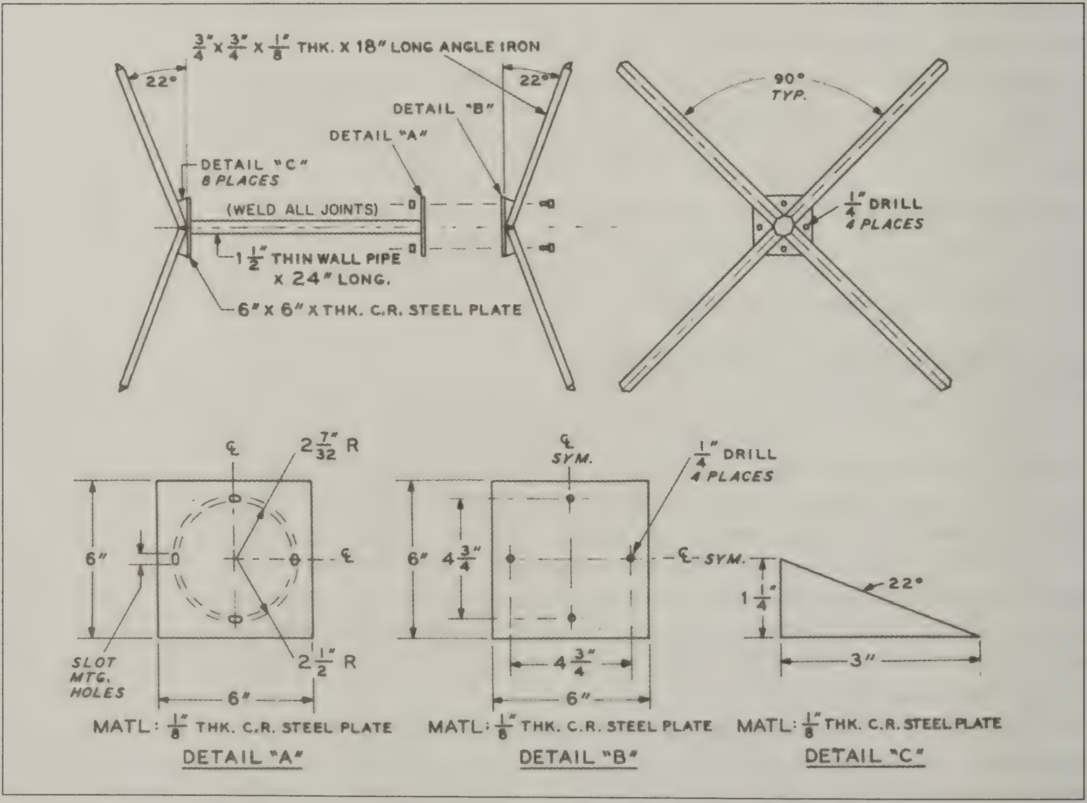


Fig 7.7: Construction details of a hub for an optimum spaced multiband quad. (from [1]).



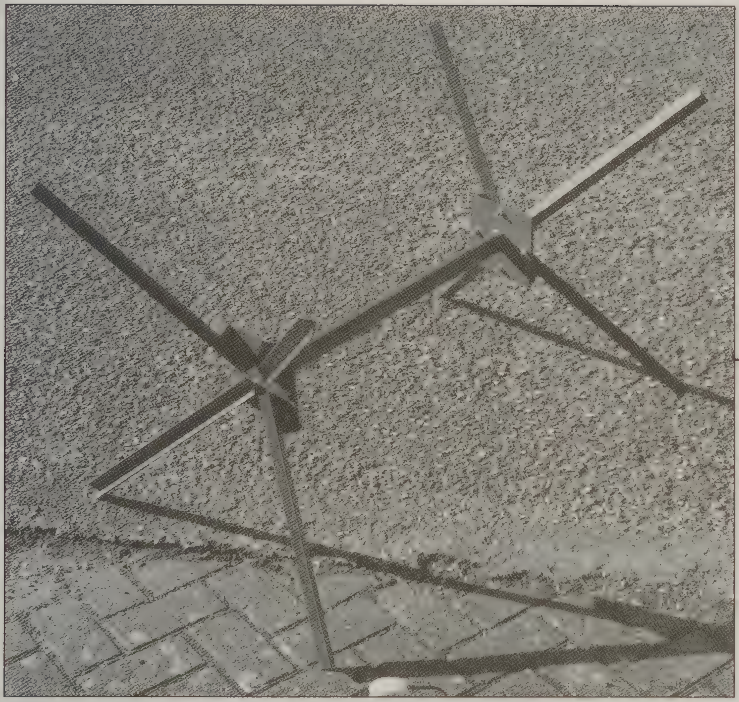
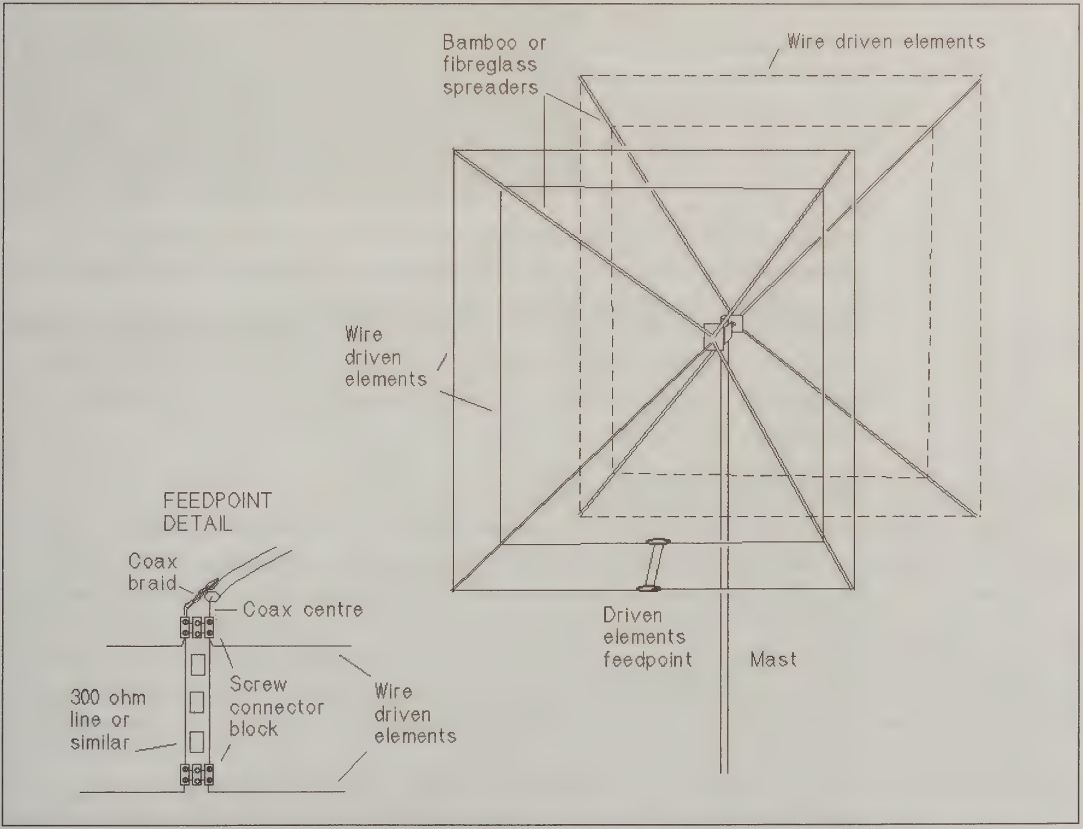


Fig 7.8: Example of the multiband quad hub constructed to the dimensions given in Fig 7.7.

Fig 7.9: A dual-band variant of the quad using optimum driven element/reflector spacing for each band. It also shows a proven way of feeding with single coax feeder.



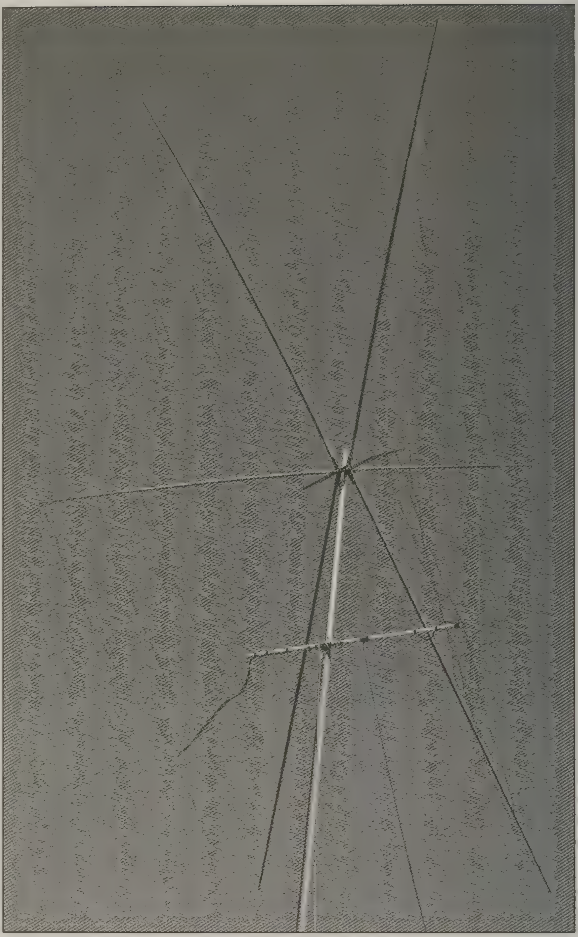


Fig 7.10: A multiband quad for the 14, 18 and 21MHz bands using the aluminium lightweight Labgear boomless spider. An extra long stub is used on the 14MHz reflector because the element supports were too short to accommodate dimension R and ES for 14MHz.

set at an angle of 22 degrees as shown in Fig 7.7. This structure is very strong and would probably support a 7MHz quad. The only down side is that it is rather heavy, weighing in at 7kg. A practical example is shown in **Fig 7.8**.

The element supports can be fixed to this hub using hose clamps as described above. A diagram of a two-band antenna for 14 and 18MHz is shown in **Fig 7.9**. Note that element support dimensions (ES, the point where the element is fixed to the support) will have to be increased by around 5% with this construction.

There are commercial hubs or spiders around that dispense with the boom altogether. Antennas using these devices are referred to as a 'boomless' quad for obvious reasons. An aluminum hub, made by Labgear, was used to construct the quad shown in **Fig 7.10**.

Methods of feeding

I was once of the opinion the driven elements could be fed in parallel without any compromise in performance. This assumption, according to W4RNL [2], is incorrect if any one of the elements on the antenna is harmonically related to one of the others. On a three-band quad for 14, 21 and 28MHz for example, when the antenna is energised on 28MHz the 14MHz element also presents a near matching impedance to the feeder being a two-wavelength loop on that band. The effect of this is to damage the desirable quad directivity pattern on the 28MHz band.

W4RNL constructed a computer model of a five-band quad using the 'spider' configuration. Each band was energised in turn and it showed that the perform-

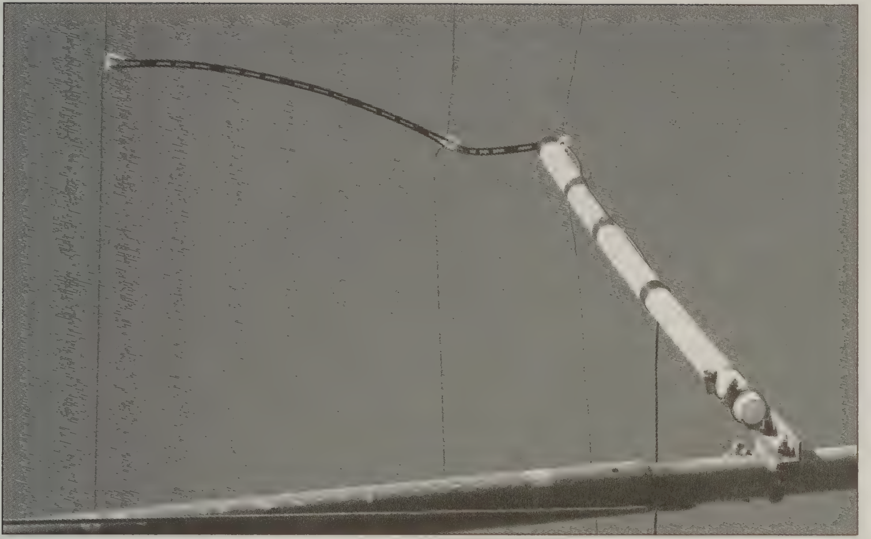


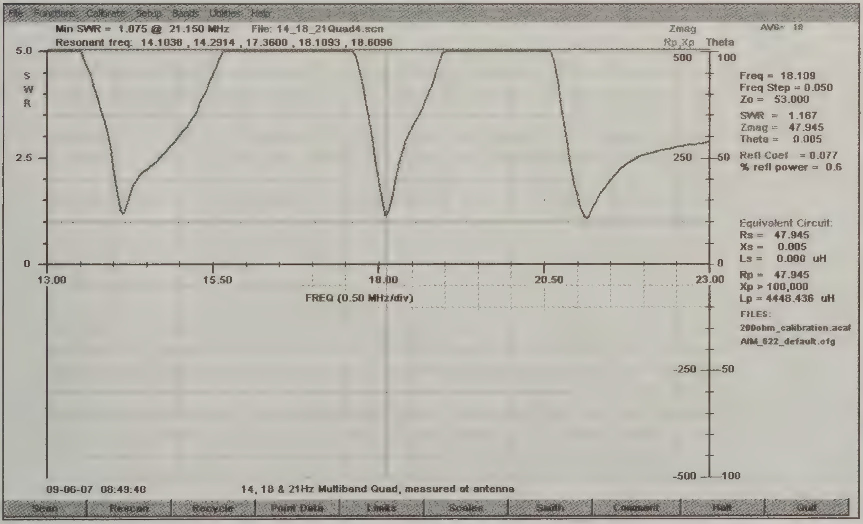
Fig 7.11: Detail of the multiband quad feed arrangement. A plastic tube is fixed to the mast to provide support for coax feeder.

ance on each individual band could be as good as a single band quad. It is probable that this is the reason many multiband quads builders use a separate feeder for each band.

To feed five bands would require quite a lot of coax cable. Because of this some quad builders have opted for a single feed arrangements, which often involve electro-mechanical devices to effect band switching.

Is there an easier way? A quad for 18 and 21MHz was constructed with the driven elements connected in parallel. It didn't work! The driven elements were then fed via a length of 300-ohm ladder line feeder with coax feed being fed to the 21MHz element as shown in Fig 7.9. This arrangement showed promise and a 14MHz quad was added. The complete antenna is shown in Fig 7.10 and with the detail shown in **Fig 7.11**.

An Antenna Analyser AIM 4170 was used plot the impedance characteristics of the antenna and the results are shown in **Fig 7.12**. The feeder characteristics



```
Min SWR = 1.075 @ 21.150 MHz     File: 14_18_21Quad4.scn
Resonant freq: 14.1038 , 14.2914 , 17.3600 , 18.1093 , 18.6096
AVG= 10

Freq = 18.109
Freq Step = 0.050
Zo = 53.000
SWR = 1.167
Zmag = 47.945
Theta = 0.005
Refl Coef = 0.077
% refl power = 0.6

Equivalent Circuit:
Rs = 47.945
Xs = 0.005
Ls = 0.000 uH
Rp = 47.945
Xp > 100,000
Lp = 4448.436 uH
FILES:
200ohm_calibration.acal
AIM_622_default.cfg

09-06-07 08:49:40          14, 18 & 21Hz Multiband Quad, measured at antenna
```

Fig 7.12: Analysis of the multiband quad using the AIM 4170 Antenna Analyser. The cursor set on 18.1MHz allows the feed impedance at the antenna to be measured - R47.9 j+.005

(length, impedance and velocity factor) were factored into the AIM 4170 so that the parameters shown in Fig 7.12 are those at the feedpoint of the antenna. Three clear points of low SWR are shown for the 14, 18 and 21MHz bands indicating that the simple matching method is working.

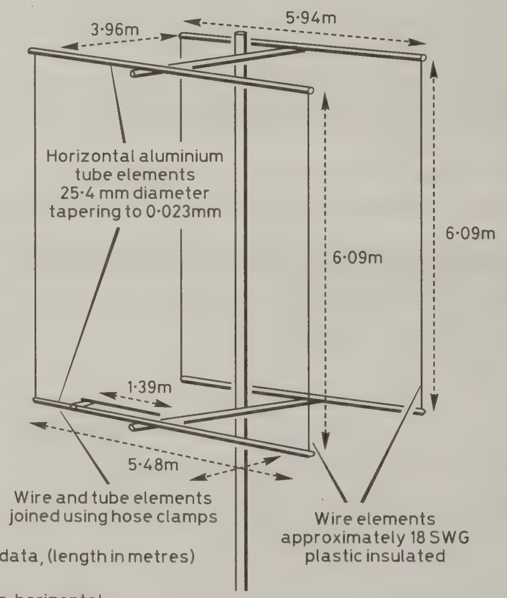
THE ALL METAL QUAD

This all metal version of the quad evolved as an attempt to make a more simple, weatherproof version. The metal quad antenna for 14MHz looks like two ten metre two-element beams stacked at half a wavelength. The tips of the elements of the bays are joined by 14SWG stranded copper wire, making full wavelength loops for the 14MHz band.

The lengths of the elements and the distance between the booms were initially set at approximately 5.5metres (18 feet); this dimension being determined by the quad formula:

L (Total element length in metres) = 306.3/f(MHz)
or
L (Total element length in feet) = 1005/f(MHz)

With these dimensions the resonant frequency of each metal quad loop was around 15.4MHz; probably due to the construction. When wire is added to the end of an aluminium tube it represents an extreme diameter taper, which causes the above formula to be inappropriate.


3·96m
5·94m
Horizontal aluminium tube elements 25·4 mm diameter tapering to 0·023mm
6·09m
6·09m
1·39m
5·48m
Wire and tube elements joined using hose clamps
Wire elements approximately 18 SWG plastic insulated
CD973

Design data, (length in metres)

Reflector, horizontal section = 83·82/f (MHz)
Driven element, horizontal section = 77·41/f (MHz)
All elements, wire vertical section = 85·64/f (MHz)
Element spacing = 55·77f (MHz)
Gammarod = 17·95/f (MHz)

Fig 7.13: Construction of a two-element all metal quad for 14MHz with design formula for other frequencies.

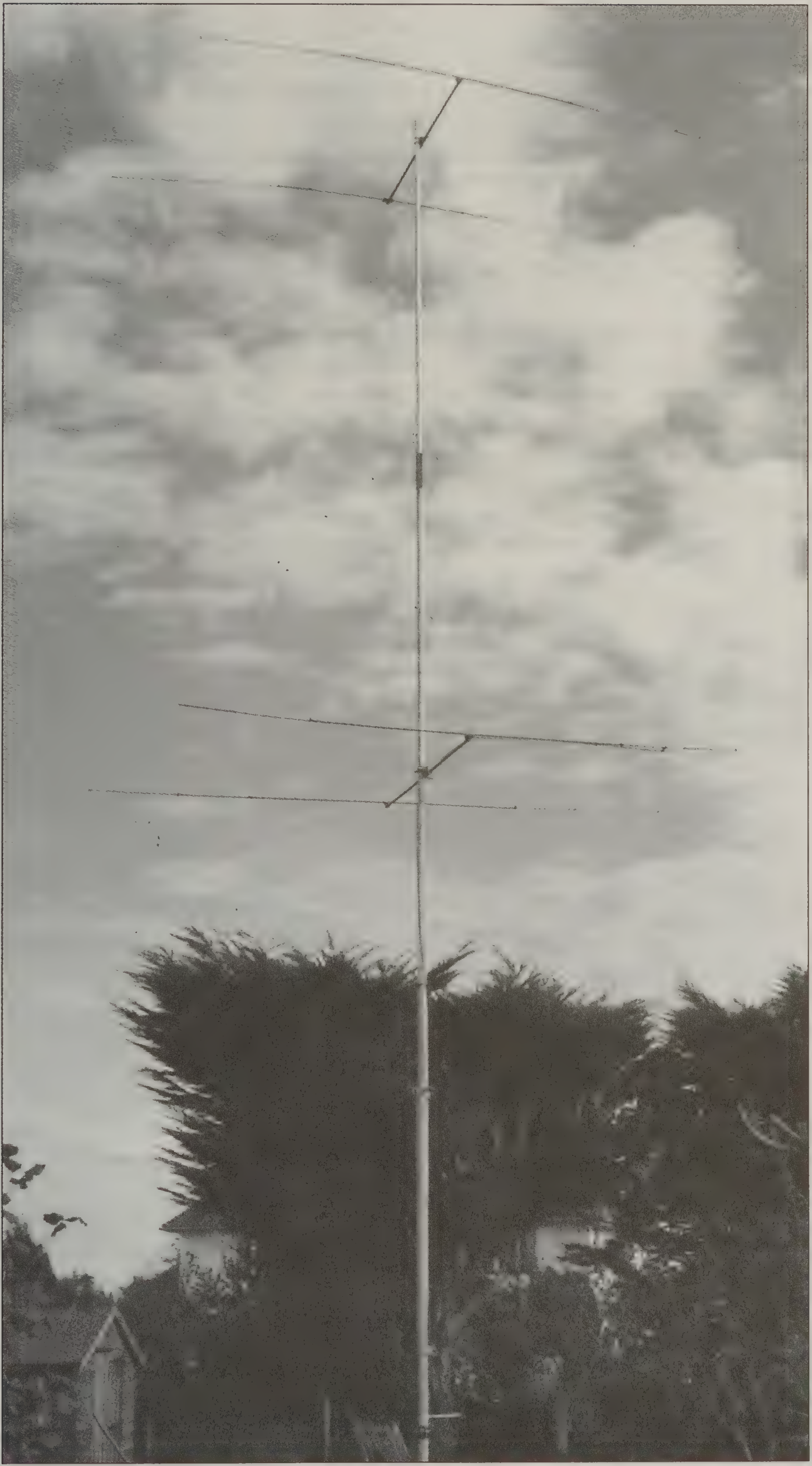


Fig 7.14: 14MHz two-element, all metal quad.

When the spacing between the bays and the vertical sections of the elements are increased to 6 metres (20 feet) the quad element resonances move down into the 14MHz band. The dimensions for a 14MHz quad are shown in **Fig 7.13**.

The reflector element can only be made longer by increasing the length of the aluminium tube horizontal sections, the final dimensions for 14MHz are 5.5 metres (18 feet) for the driven element and 5.94 metres (19ft 6in) for the reflector. The driven element can be fed directly in the centre with 50-ohm coax or via a matching system such as a Gamma match (see chapter 11).

All measurements indicate that the gain is greater than that of conventional quad.

This structure is neater, and has a smaller windage, than the conventional wire quad on spreaders, see **Fig 7.14**. The main disadvantage of this configuration is that it is a single band antenna. It also requires a section of unguyed mast above the rotator. The unguyed rotating mast described in Chapter 10 is the most suitable support for this antenna.

REFERENCES

[1] *All about cubical quad antennas*, Bill Orr, W6SAI and Stuart Cowan, W2LX.

[2] L B Cebik, W4RNL, http://www.cebik.com.

8

Loop and slot antennas

If space at your QTH is very restricted, with no place to put up a wire antenna, a small HF transmitting loop antenna may be an option. Reasonable antenna efficiency on a small loop can be achieved only by ensuring the loop has a very low RF resistance. Additionally its high-Q characteristic results in a narrow effective bandwidth, requiring accurate retuning for even a small change in frequency. This can be overcome by the use of complex and expensive automatic tuning systems or, more realistically for amateurs, by remote control of the tuning capacitor forming part of the loop. Another disadvantage is that even on low-power, there will be very high RF voltage across the tuning capacitor, resulting in the need for either a high-cost vacuum capacitor or a good-quality, wide-spaced transmitting capacitor.

Against these disadvantages should be set the fact that a well-constructed loop can be surprisingly effective. Furthermore, the short loop utilises the near-field magnetic component of the electromagnetic wave resulting in much less RF absorption in nearby objects: this means that a short loop can be used successfully indoors or on a balcony. For reception a 'magnetic' antenna is much less susceptible to the electric component of nearby interference sources. The reduction of man-made noise is particularly important on the lower-frequency bands, and is further enhanced by the directional properties of a loop. The loop can work effectively without an artificial ground plane.

The high-Q characteristic of a low-loss loop also means that it forms an excellent filter in front of a receiver, reducing overload and cross-modulation from adjacent strong signals. On transmit, these properties dramatically reduce harmonic radiation and hence some forms of TVl and BCI.

Not all the loop antennas described in this chapter are physically small. Larger loops have greater efficiency (all other things being equal) so if you do make a loop antenna use the largest loop that your location allows.

Basics

To achieve good radiation efficiency in a small transmitting loop it is essential to minimise the ratio of RF ohmic losses to radiation resistance. In a small resonant loop the RF ohmic losses are made up of the resistance of the loop and that of the tuning capacitor (which will have much lower resistive loss than a loading coil). The tendency of HF current to flow only along the surface of a conductor (skin effect) means that large diameter continuous copper tubing (or even silver-plated copper) should be used to achieve a maximum high-conductivity surface area.

Provided that the circumference of a loop is between 0.125λ and 0.25λ, it can be tuned to resonance by series capacitance. If the loop is longer than 0.25λ it will lose its predominant 'magnetic' characteristic and become an 'electric' antenna of the quad or delta type. However, unless the loop is less than one wavelength in circumference it will still have a relatively low radiation resistance.

The radiation resistance of a small loop is governed by the total area enclosed and is a maximum for circular loop. It is possible to build a transmitting loop antenna with a circumference less than 0.125λ but in these circumstances special attention must be paid to the tuning and matching arrangements as described in the PA2JBC 80metre design, described later. More conventional designs require that the operating range of a transmitting loop is restricted to a ratio of 1:2, that is to say 3.5 to 7, 7 to 14, or 14 to 28MHz. Extending the tuning range will tend to result in a rapid falling off in efficiency. The most convenient solution for complete HF coverage is to use two loops; one for the higher frequency bands (14, 18, 21, 24 and 28MHz), the other for 3.5 and 7MHz or 7 and 10.1MHz. For 1.8MHz it is advisable to use a loop designed for this band, or for 1.8 and 3.5MHz.

A WIRE LOOP FOR THE LOWER HF BANDS

As already mentioned, it is necessary to ensure that the resistance of the loop is as low as possible.

However, larger loops for the HF bands may be impractical due to the weight. C R Reynolds, GW3JPT, constructed many magnetic loop antennas, all of which were made from 22mm copper tubing or strip aluminium. Some of the experimental loop antennas he used are shown in **Fig 8.1**.

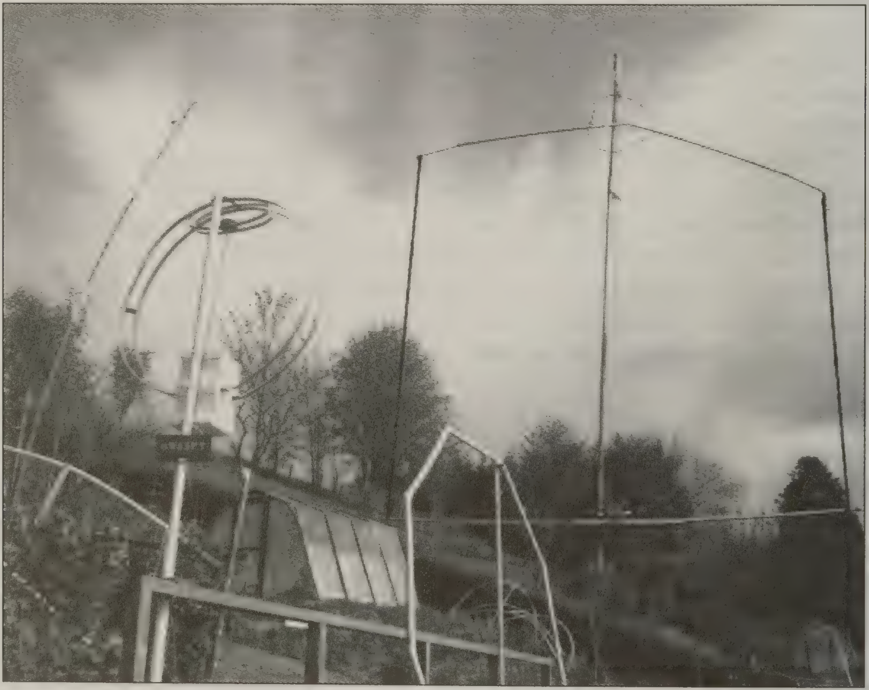
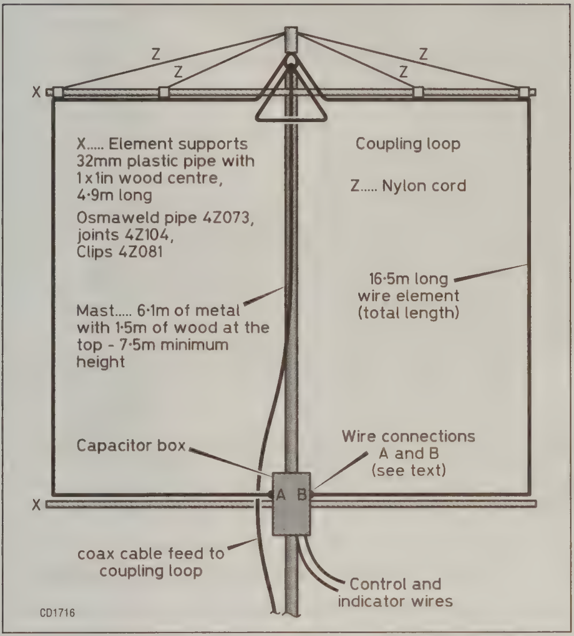
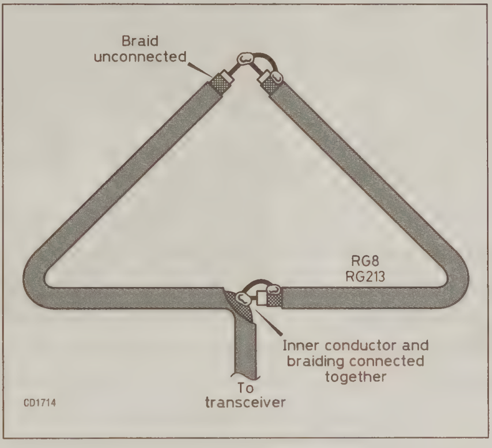


Fig 8.1: Some experimental loops used by GW3JPT.


Z
Z
Z
Z
X
X..... Element supports 32mm plastic pipe with 1x1in wood centre, 4·9m long
Osmaweld pipe 4Z073, joints 4Z104, Clips 4Z081
Coupling loop
Z..... Nylon cord
16·5m long wire element (total length)
Mast..... 6·1m of metal with 1·5m of wood at the top - 7·5m minimum height
Capacitor box
Wire connections A and B (see text)
A
B
X
coax cable feed to coupling loop
Control and indicator wires
CD1716

(left) Fig 8.2: Overall view of the LF band magnetic loop.

(below) Fig 8.3: The Faraday coupling loop



He wanted to operate on the lower HF frequency bands and although he found that it was possible to tune a small loop to top band using a very large 1000pf capacitor there were two problems. On 160 metres the efficiency is rather low and on 40 metres tuning is rather critical because it only takes a few picofarads of tuning capacitor variation to tune the whole of the 40m band. This represents a very small percentage of 1000pF, requiring only a fraction of capacitor rotation to cover the band.

GW3JPT described a different design of a practical loop antenna for the 160, 80 and 40 metre bands [1]. This uses a much larger square loop of a size shown in **Fig 8.2**. If this were to be made from copper tube it would be very heavy so he used a 19.5m (64ft) length of plastic covered wire. This antenna requires a 250-300pF tuning capacitor.

The Faraday coupling loop is shown in **Fig 8.3**. It is close coupled for about 0.77m (30in) each side of the centre of the triangle section of the element.

This wire loop will also work on 40m. This is done by using a relay or a switch to disconnect the capacitor at points A and B, as shown in Fig 8.2. The loop is then tuned by the stray capacitance of the switch or the relay. Because this stray capacity cannot be varied, the antenna element length is adjusted for correct matching using an SWR meter.

The antenna and mast can be fitted to a good ground post. It does not need any guy wire support and can be raised or lowered easily. For portable use it can be erected in a few minutes using three or four guy wires.

Capacitor drive motor

There are motors available suitable for rotating the loop capacitor. The cheapest and one of the best available is a barbecue spit motor. Although this is already geared down it does require extra reduction using a 6:1 or 10:1 epicyclic drive for more precise tuning.

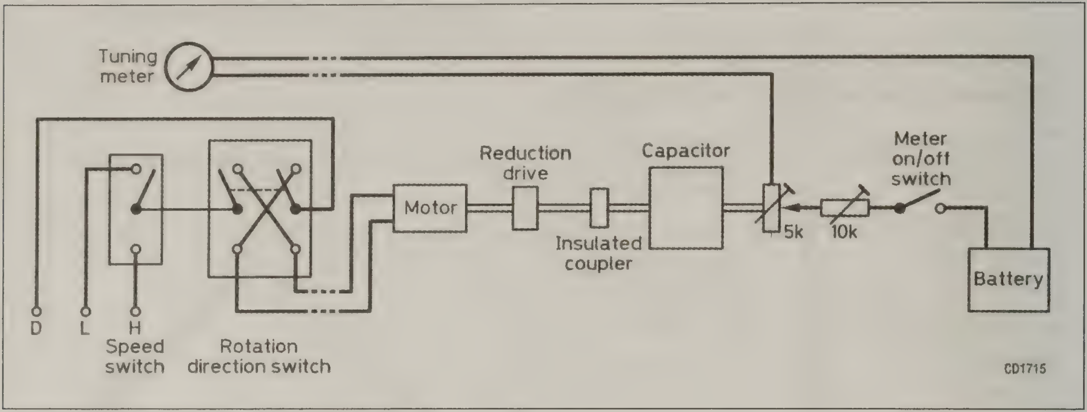


Fig 8.4: Control and indicator system for the magnetic loop antenna.

The motor will rotate slowly if energised by a 1.5 volt battery. With 3 volts applied the motor will run much faster. By switching from 1.5 to 3 volts a fast or slow tuning speed can be selected. This switching is shown in **Fig 8.4**. The positive lead of the 3V battery is connected to H and the positive lead of the 1.5V battery is connected to L. The negative leads of both batteries are connected to D.

The direction of rotation is achieved using a two-pole, three-way switch. When the switch is set to the centre position the motor is disconnected from the battery (OFF position).

The battery polarity to the motor is selected by the two other positions of the switch and should be labelled DOWN or UP.

The drive mechanism must be electrically isolated from the high RF voltages present at the capacitor. An insulated coupler can be made from plastic petrol pipe.

This pipe size should be chosen so that it is a push fit on to the drive mechanism and capacitor shafts. The pipe can then be fixed to the shafts by wrapping single strand copper wire around the ends of the pipe and tightening with a pair of pliers.

All the capacitors made by GW3PJT have the spindle extending both sides of the capacitor. One spindle is used to couple the capacitor to the drive mechanism. The other is used to connect the capacitor to a position indicator. This indicator circuitry must be electrically isolated from the capacitor as described above.

The control unit is housed in a plastic box. The fast/slow and rotation direction switches are fixed to the front, together with the capacitor position meter.

Capacitor unit housing

One of the main problems of constructing any electrical circuits associated with antennas is protecting them from wind and rain. One option is to try and find some sort of suitable plastic housing and then organising the components to fit, but GW3JPT prefers to make the tuning housing from exterior plywood. The bottom and sides of the box are fixed together using 1in square strips of timber. Glue and screws are used to make the joints water-proof. The top must, of course, be made so that it can be removed fairly easily. Paint or varnish the box as required.

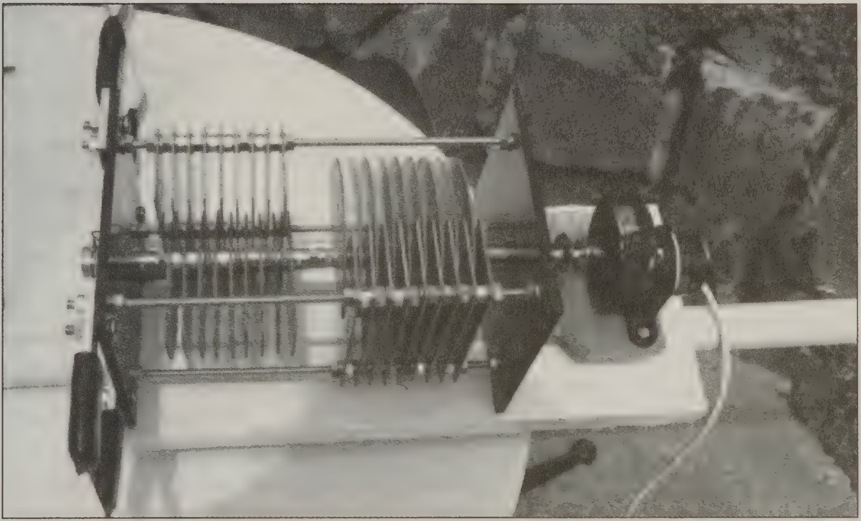


Fig 8.5: An example of one of GW3JPT home-made capacitors.

Construction of capacitors

The capacitors for tuning loop antennas are very difficult to come by so GW3JPT makes his own and an example of one of his home made capacitors in shown in **Fig 8.5**

GW3JPT used aluminium and double-sided circuit board for the vanes, and nuts and washers are used for the spacers. Various types of insulation material can be used for the end plates.

The centre spindle and spacing rods are constructed from 6mm threaded plated steel rod.

Make the 76mm x 76mm (3 x 3in) end plates first, see **Fig 8.6**. These can be taped together back-to-back for marking and drilling. The same can be done with the vanes. Masking tape is used so the surface is not scratched around drill holes, which are drilled to clear 6mm with the centre hole acting as a bearing.

The number of vanes required dictates the length of the 6mm spindle. For double-sided board use washer/nut/washer spacers can be used so that there is no need to bond the copper sides. The resulting spacing of about 6mm (0.25in).

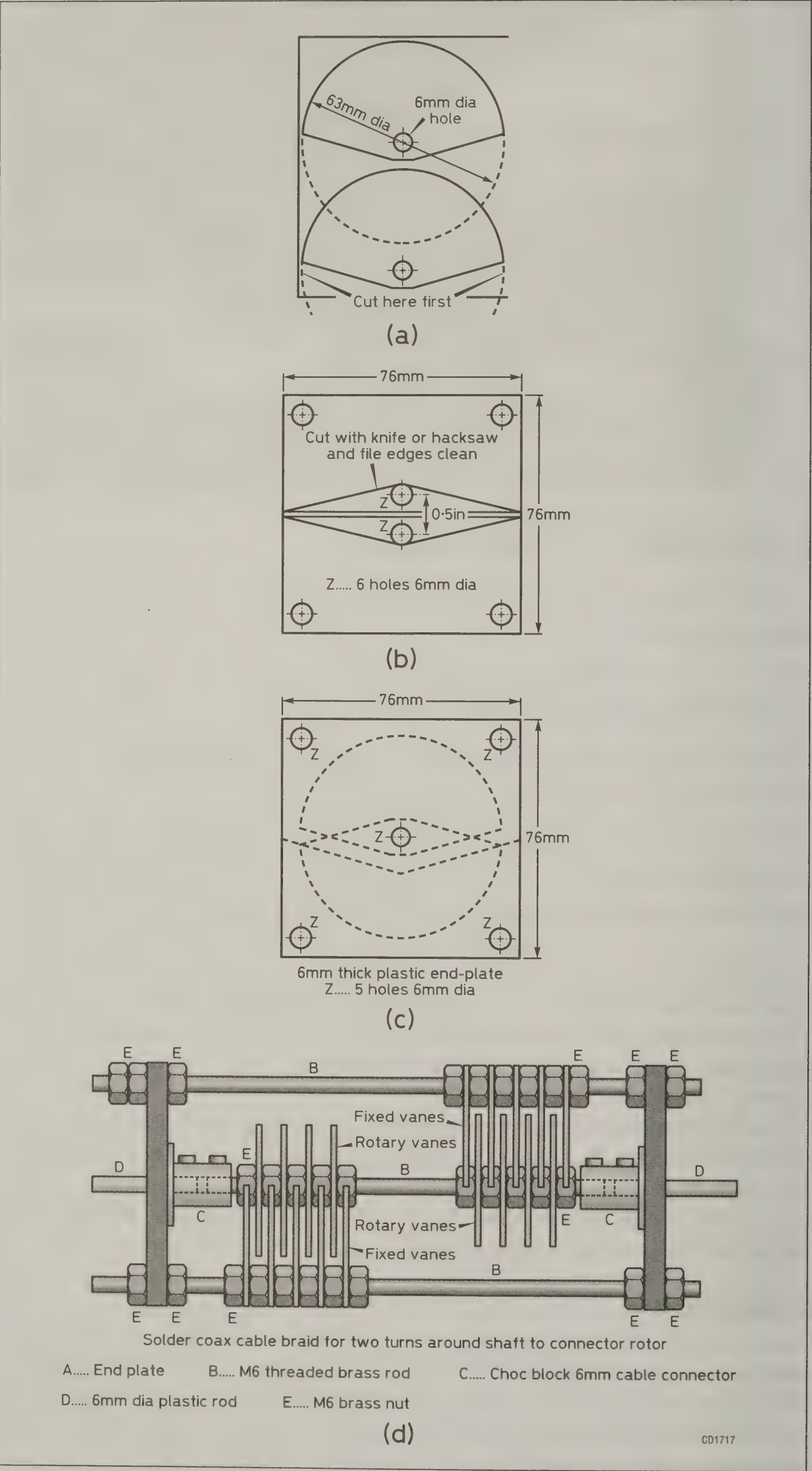
The first capacitors made by GW3JPT used the conventional shape for the moving vanes, but this is very difficult to cut out and fragile to use. The shape illustrated in Fig 8.6 (a) is much easier.

The fixed vane is a simple rectangle, which can be modified to reduce the minimum capacity. (Dotted line Fig 8.6(c). For the size shown six pairs of vanes with 6mm (0.25in) spacing work out to about 150pf. Units using both printed circuit board and aluminium vanes have been in use for over two years and they are both still in good working condition.

Operation

Tuning of the loop needs to be adjusted precisely for minimum SWR, which should coincide with maximum power out. This tuning is critical; a few kilohertz off tune and the SWR will rise dramatically. The best way of finding the correct position of the tuning capacitor is to listen for maximum noise, or signals, whilst tuning the loop. Then fine-tune using an SWR meter.

Fig 8.6: Details of home-made capacitor; (a) moving vanes; (b) fixed vanes; (c) fixed and moving vanes geometry showing minimum capacitance; (d) capacitor assembly.


63mm dia
6mm dia hole
Cut here first
(a)
76mm
Cut with knife or hacksaw and file edges clean
Z
0·5in
Z
76mm
Z..... 6 holes 6mm dia
(b)
76mm
Z
Z
Z
Z
Z
76mm
6mm thick plastic end-plate
Z..... 5 holes 6mm dia
(c)
E
E
B
E
E
E
Fixed vanes
Rotary vanes
E
D
B
D
C
Rotary vanes
E
C
Fixed vanes
B
E
E
E
E
E
Solder coax cable braid for two turns around shaft to connector rotor
A..... End plate
B..... M6 threaded brass rod
C..... Choc block 6mm cable connector
D..... 6mm dia plastic rod
E..... M6 brass nut
(d)
CD1717

The performance of this antenna on 80m was at least as good as my G5RV. It tuned all of top band and gave quite good results as compared with local signals on the club nets.

A TWO-METRE DIAMETER LOOP FOR 80M

This loop antenna is very compact and although designed for mobile use it would be suitable for 80m operation from a very restricted location. It was designed by PA2JBC [2] to have a diameter of 2m and, for transportation purposes, be capable of being dismantled into two pieces. This feature would make it easy to get through a small loft access hatch. It also has a most interesting tuning arrangement. However, bearing in mind what has already been said about loops, an antenna this small does not have the efficiency of the larger models. The specification of the PA2JBC loop is given in **Table 8.1**

The electrical characteristics in the Table 8.1 were calculated for 22mm copper tubing. For practical reasons this antenna was built as an octagon. Measurements on the final antenna correlated closely with the calculations in Table 8.1 and PA2JBC has concluded that soft-soldered (rather than brazed or silver soldered) 45 degree elbows and the compression couplers do not spoil the Q. The structure of the antenna is shown in **Fig 8.7**.

The eight 820mm lengths of copper tubing are prepared by thoroughly cleaning the ends with fine emery paper and coating with flux. The pipe must be cut with a pipe cutter so that the ends fit snugly into the connector.

Two of the pipes to be joined are fitted into the 45° connecting elbows. The joint is heated with a blowtorch while at the same time applying multi-cored solder at the point where the pipe joins the connector. When the solder flows freely the joint is complete.

Repeat for all the other joints, making sure the alignment of the loop is flat and make sure you fit the current transformer on to one of the sections of tubing (see later) before completing the loop. The completed loop is then cut in two sections as shown in Fig 8.7 and compression joints fitted at point A. If the antenna has to be frequent dismantled and reassembled then the 'olive' should be soldered to the tubing to reduce wear.

L	5.8µH
Loaded Q	1273
Resistance	7.4mΩ
Loss resistance	46mΩ
Efficiency	14%
Bandwidth -3dB	2.94kHz
C at resonance	314pF
Capacitor volts	8.3kV
Loop current	43.3A RMS

Table 8.1: Calculated data for the PA2JBC 80m, 2m diameter loop antenna using 22mm tubing, using a 100W transmitter at 3.74MHz.

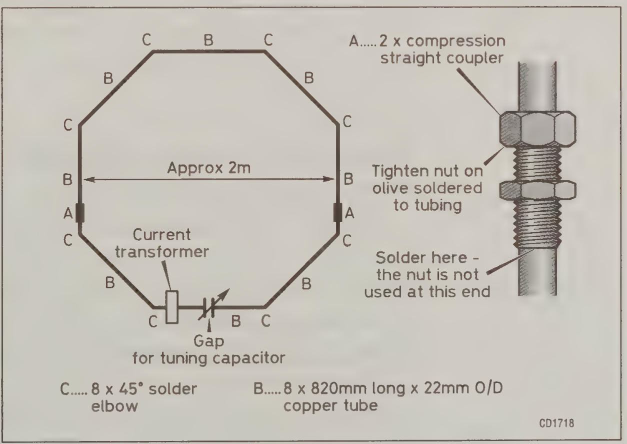

C
B
C
A.....2 x compression straight coupler
B
B
C
C
Approx 2m
B
B
Tighten nut on olive soldered to tubing
A
A
C
C
Current transformer
Solder here - the nut is not used at this end
B
B
C
B
C
Gap for tuning capacitor
C.....8 x 45° solder elbow
B.....8 x 820mm long x 22mm O/D copper tube
CD1718

Fig 8.7: The PA2JBC 80m compact loop antenna.

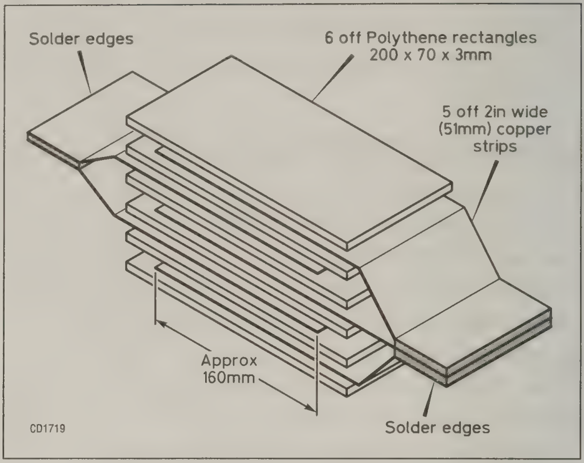


Fig 8.8: This fixed 260pF home made capacitor is good for 8kV @ 40A.

The tuning capacitor

The required capacity variation to cover 3.5 - 3.8MHz is 300pF to 360pF. This capacitance is made up using a fixed capacitor of 260pF and a 100pF maximum variable in parallel. Using a small variable capacitor reduces the cost and improves the band-spread tuning.

The 100pF variable must be able to handle up to 9kV peak and 13A RMS when used with a 100W transmitter. A wiper connection to the rotor is unsuitable at 13A so a 2 x 200pF split-stator capacitor is used. Even then, the current path between all rotor plates must be low resistance, preferably soldered or brazed; the same goes for the stator plates and their connections to the loop tubing. At 9kV, conservative design requires 9mm spacing between the plates, or 4.5mm in a split-stator (each half takes 50% of the voltage).

The fixed capacitor is made from 51 x 0.3mm copper strips interleaved with slabs of dielectric as shown in **Fig 8.8**. Polyethylene works well as a dielectric and is inexpensive; if it gets hot, it is not polyethylene! The capacity is set by adjusting the meshing of the two sets of copper 'plates' but the dielectric must extend beyond the copper by at least 6mm. After adjustment, the capacitor can be wrapped with glass-fibre-reinforced tape. Four parallel 3mm copper wires connect the fixed capacitor to the loop tubing. The 3mm-thick polyethylene is just adequate for 100 watts. On test the power was increased to 180W before it broke down.

Loop-to-feeder coupling

With a loop of this design PA2JBC could not get a gamma-match to work. A coupling loop also proved unsatisfactory as its shape had to be adjusted when changing frequency. The final solution was a current transformer. This transformer must match the 53 milliohm loop to a 50-ohm coax, an impedance ratio of 940:1 - a turns ratio of $\sqrt{940} \approx 30:1$. With this transformer the '1' is the loop tubing fixed in the centre of a toroid. With the loop at resonance the feeder 'sees' inductance.

By increasing the transformer winding to 36 turns and adding a series capacitor a 1:1 SWR can be obtained anywhere in the band. This capacitor is a receiver-type air-dielectric 250pF variable. A 1:1 balun keeps the outside of

Fig 8.9: An electrical diagram of the matching transformer and balun.

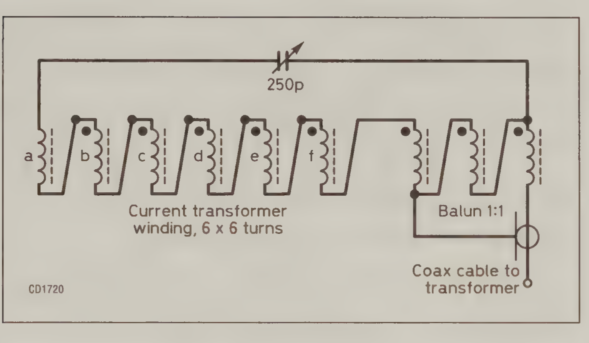
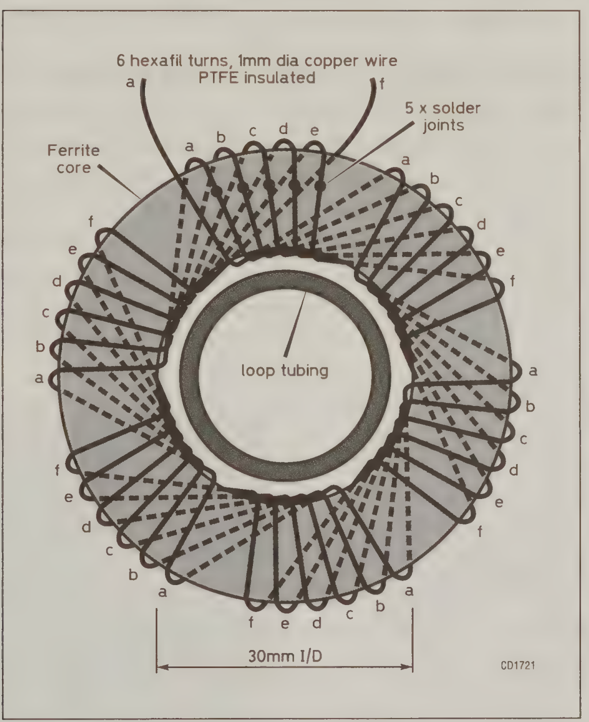

250p
a
b
c
d
e
f
Current transformer winding, 6 x 6 turns
Balun 1:1
Coax cable to transformer
CD1720

Fig 8.10: Construction of the current transformer



the coax 'cold'. An electrical diagram of the transformer and balun is shown in **Fig 8.9**.

Construction of the current transformer is shown in **Fig 8.10**. It comprises 6 x 6 turns of 1 mm PTFE-insulated copper wire gave the best results. Ferrite (Philips 4C6, violet) and iron powder (Amidon, red) both gave good results. The transformer can be placed anywhere on the tubing, eg next to the capacitors where they and the coupler can housed be in a weatherproof box.

Installation and operation

PA2JBC installed the antenna in his loft 3m above ground level and above all the electrical wiring. It should be fixed using good insulating material such as plastic pipe. The antenna's location close to wooden rafters and clay roofing tiles does not noticeably affect the Q of the loop, even when the roof is wet. If the loop is rotated with a TV rotator then it can be used to null out sources of interference.

With 100W PEP, only 14W is radiated from this indoor antenna, which is probably as good as the best mobile antenna for the band. Certainly there is no problem with normal 80m countrywide QSOs in the daytime and occasional DX contacts at night. The high-Q characteristics of the antenna give a marked improvement in the signals to noise ratio in the presence of general electrical interference and QRN. This antenna could be used as a 'receive only' antenna in conjunction with a larger antenna for DX.

Tubing of 28mm would raise the Q and efficiency but it would also reduce the bandwidth; fine for CW, but too narrow for 80m SSB! As it is, the loop must be re-tuned for every change of frequency.

For outdoor use, the loop should be de-greased and painted.

ROOF-SPACE MULTI-BAND MAGNETIC LOOP

The following is yet another example of a loft antenna, which has the distinction of being able to operate from 80 to 10m. It was described by Eric Sandys, GI2FHN [3]. The main loop and the coupling loops are made from coaxial cable although the type, and hence the diameter, is not specified. It can be safely assumed that the larger diameter cable, such as RG213 will give a more efficient antenna than the thinner varieties, although it will be more critical to tune. The antenna design borrows the dual tuning technique from the Z-match tuner. The circuit of the loop is shown in **Fig 8.11**.

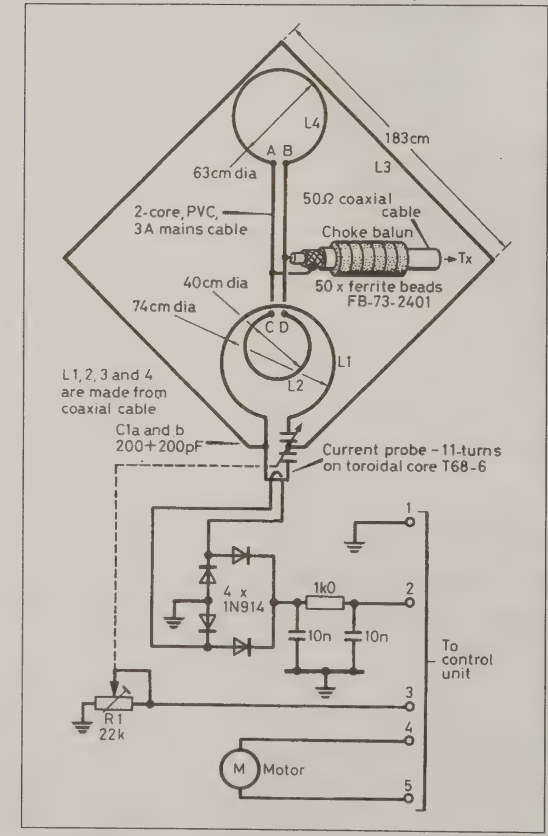

183cm
L4
A B
63cm dia
L3
50Ω coaxial cable
2-core, PVC, 3A mains cable
Choke balun
Tx
50 x ferrite beads FB-73-2401
40cm dia
74cm dia
C D
L1
L2
L1, 2, 3 and 4 are made from coaxial cable
C1a and b 200+200pF
Current probe - 11-turns on toroidal core T68-6
1
4 x 1N914
1k0
2
10n
10n
To control unit
3
R1 22k
4
M
Motor
5

Fig 8.11: GI2FHN's dual magnetic loop for 3.5 to 28MHz.

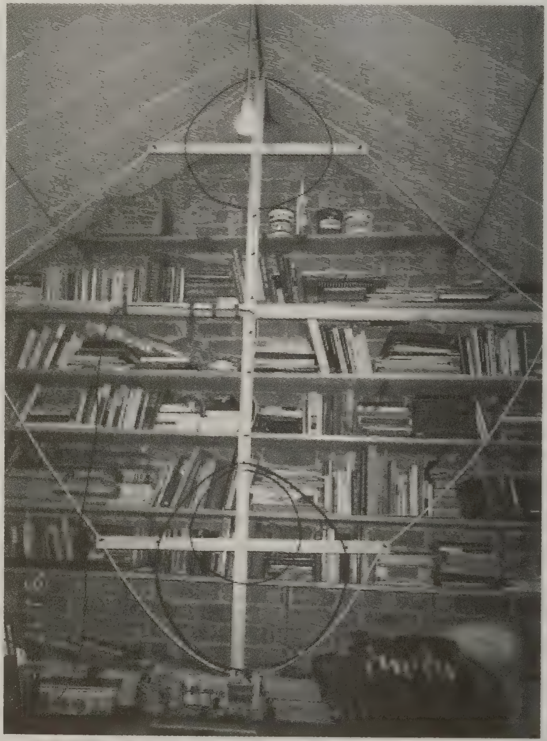


Fig 8.12: The multiband loop antenna located in the roof space at GI2FHN.

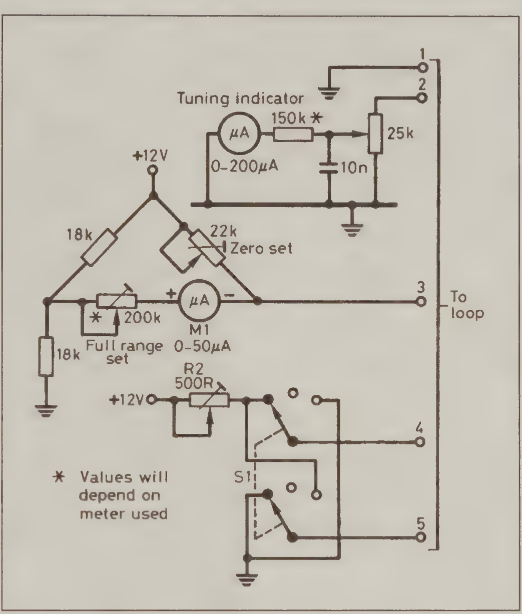


Fig 8.13: Control and indicator unit for tuning the GI2FHN dual loop.

On 14, 18, 21, 24 and 28MHz, L1 is tuned by C1a and C1b in series. Because L3 presents high impedance at these frequencies it can be ignored. On 3.5 and 7MHz, L3 is tuned by C1a placed in parallel with C1b through L1.

The coupling links L2 and L4 are connected in parallel and RF is fed in through a 1:1 choke balun. The diameters of the coupling links were selected to give the lowest SWR, which is better than 1.5:1 on all bands. If coverage of the 10MHz band is required, L4 needs to be reduced slightly in size.

The diameter of the coaxial cable is used for the loops and coupling links should be the same. Note that the connections between the two coupling links should not be transposed. A should go to C and B to D. Failure to observe these points can result in degradation of the SWR.

At GI2FHN the loop was housed in the roof space using a timber framework to provide the necessary support, see **Fig 8.12**.

All frequency adjustments are carried out from a control box (**Fig 8.13**) at the operating position. Changing bands is made easy by using a Wheatstone bridge to give a visual indication on Ml of the travel of C1. The variable arm R1 is gear driven from the shaft connecting the motor and reduction gearing to C1. The direction of rotation is controlled by S1, a DPDT switch (centre-off). Fine-tuning is provided by a speed control R2. A current probe enables exact resonance to be established at the operating frequency.

GI2FHN found that results exceeded all expectations and the arrangement can be recommended for anyone who has a loft space but does not have space for a full size wire antenna.

COMMENTS ON SMALL LOOP ANTENNAS

As already discussed, compact loop antenna is a viable solution for these not able to erect a wire antenna. A well constructed conventional compact metal loop should not be more than about 4 or 5 dB down on a dipole half a wavelength high. This is less than one S point, however, under normal HF fading conditions difficulties might be experienced when making comparisons.

The compact wire loop by GW3JPT is about 60% efficient on 160m. Making comparisons on this band is even more difficult - getting a 160m comparison dipole up half a wavelength high is a challenge.

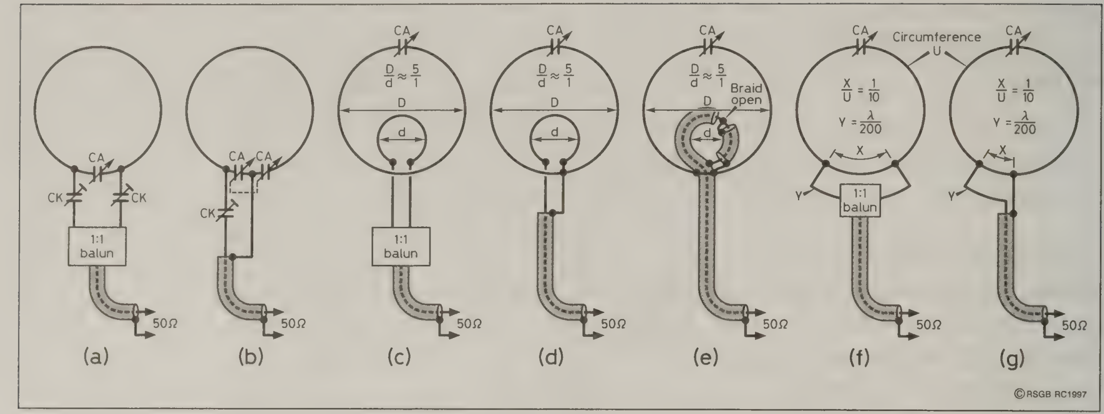


Fig 8.14: matching a transmitting or receiving antenna to 50-ohm coaxial cable as described in 1983 by DL2FA and reported in TT, October 1996. The Faraday loop method (e) is favoured, but see text.

There are numerous ways of coupling a low-impedance loop to coaxial cable and most of these are shown in **Fig 8.14**. The favoured method, the traditional Faraday loop shown in Fig 8.14(e) may not be the best. The coax inner and braid at the top or apex of the loop in Fig 8.3, for example, is shown joined, which would make a Faraday half loop. The inner to braid connection should be removed but the gap in the braid halfway round the loop should remain.

The matching methods in Fig 8.14 (a) and (b) have been used with 10m or more diameter loops for 136kHz, for both transmit and receive. The PA2JBC compact loop for 80m, with its transformer and balun, is worthy of further development for more conventional sized loops.

MULTI-BAND DELTA LOOP ANTENNA

If you have the space, a large loop antenna can be very effective. If the loop is larger than 0.25λ it will lose its predominant 'magnetic' characteristic and become an 'electric' antenna of the quad or delta type. From the previous descriptions of loop antennas it can be seen that the efficiency improves with an increase in size and the resistive losses of a loop full wavelength circumference are very small.

A full wave loop on 7MHz can be fed with coax and will also operate on the 14, and 21MHz bands and without an ATU, provided that a transformer and balun is connected between the coax and the antenna. The shape of the loop is not too important.

If a loop antenna in the form of an equilateral triangle is used then only one support is required. If this support were a mast fixed to the chimney then it can probably circumvent planning restrictions.

The antenna is shown in **Fig 8.15**. As you can see, part of this antenna is close to the ground. This means there is a possible danger of someone receiving an RF burn if the antenna is touched when the transmitter is on. For this reason insulated wire for the lower half of the antenna is recommended. A loop antenna is not a high Q device so very high voltages, such as those found at the tips of a dipole, do not occur.

The top half of the antenna can be constructed with bare copper wire. You could use insulated wire for all the loop, however lightweight wire for the upper half of the loop, and a lightweight support, has a low visual impact. Using lightweight thin wire does not affect the antenna performance because the radiation resistance of a loop is fairly high. For example, the calculated gain (including earth reflected gain) of a 7MHz loop constructed from 3mm diameter wire was just over 6dBi. The same loop constructed from 0.3mm wire gave a gain of 5.8dBi, a loss of only 0.3dBi.

The first experiments were carried out with the coax connected directly to the loop but the SWR was over 3:1. However most literature puts the feed impedance of a loop greater than 100 ohms. A 4:1 balun was fitted, see Chapter 11, enabling the antenna fed directly with 50-ohm coax with minimum mismatch.

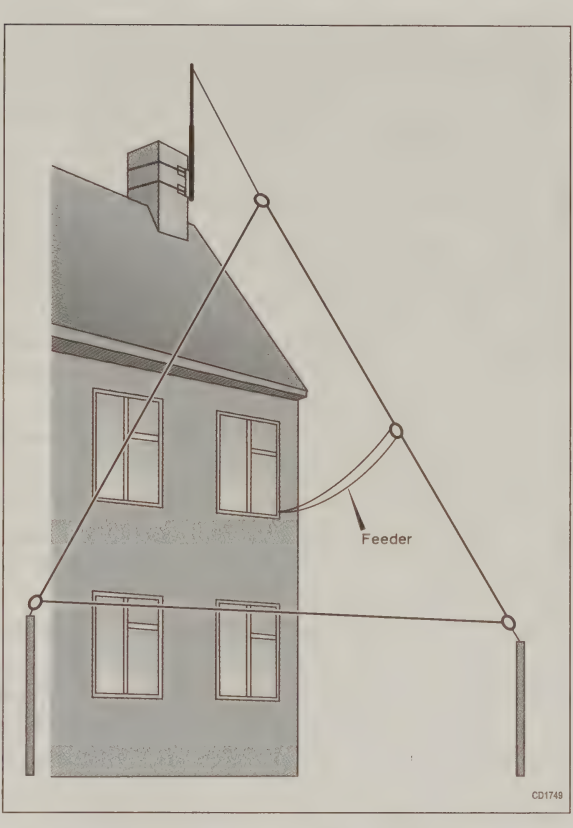


Fig 8.15: Loop antenna one wavelength circumference on 7MHz.

The best results occurred, when the antenna was fed about one third up from the bottom on the most vertical of the triangle sides. This antenna will give good results even when the lowest leg of the triangle is only 0.6m from the ground. Fig 8.15 shows the corner insulators fixed to the ground with tent peg type fixtures. It can be run along a fence with shrubs and small trees being used for fixtures for the lower corner insulators.

The apex support in the experimental model was a 2.5m length of scaffolding pole fixed to the chimney with a double TV lashing kit.

The top of the chimney is about 9m above the ground. The pole gives the antenna enough height and a reasonable clearance above the roof. The apex of the loop is nearly 11 metres high.

This antenna proved to be a good DX transmitting antenna on 7MHz although it does tend to pick up electrical noise from the house on receive. It could be used with a smaller receive loop if electrical noise or QRM is a problem.

SKELETON SLOT ANTENNA

This is a loop antenna with a difference and is known as the Skeleton Slot. With the dimensions given it will operate on the 14, 18, 21, 24 and 28MHz bands using a balanced ATU

It is very easy to construct and is a simple design with no traps or critical adjustments. This antenna has a turning radius of only 1.5m (5ft) although it is 14m (47ft) tall. However its construction means that it has a much lower visual impact than a conventional multi-band beam. The antenna is bi-directional and has a calculated gain, over average ground, of 8dBi on 14MHz and 11dBi on 28MHz.

The Skeleton Slot Antenna was first documented in an article by B Sykes, G2HCG, in January, 1953 [4].

A non-resonant slot for HF

The main exponent of the HF Skeleton Slot, other than G2HCG, is Bill Capstick, G3JYP, whose version of this antenna was described in [5].

My own version of the HF Skeleton Slot uses wire for the vertical elements, resulting in a more simplified and rugged construction. I was at first concerned that this method of construction would not work because [4] and [5] gave minimum tube diameters for the elements. However, computer modelling with EZNEC2 reassured me that this method of construction would be suitable for this particular application so I went ahead.

The antenna essentially comprises three aluminium tube elements fixed to the mast at 4.6m (15ft) intervals, with the lowest element only 4.6m from the ground. The mast is an integral part of the antenna, as a boom is to a Yagi. The general construction is shown in **Fig 8.16**.

The centre element is fed in the centre with balanced feeder and the upper and lower elements are fed at the ends by copper wire from the driven dipole

The aluminium tubing and copper wire are fixed using hose clips. These dissimilar metal connections present no corrosion problems, even in a location like mine close to the sea, provided they are well coated with grease.

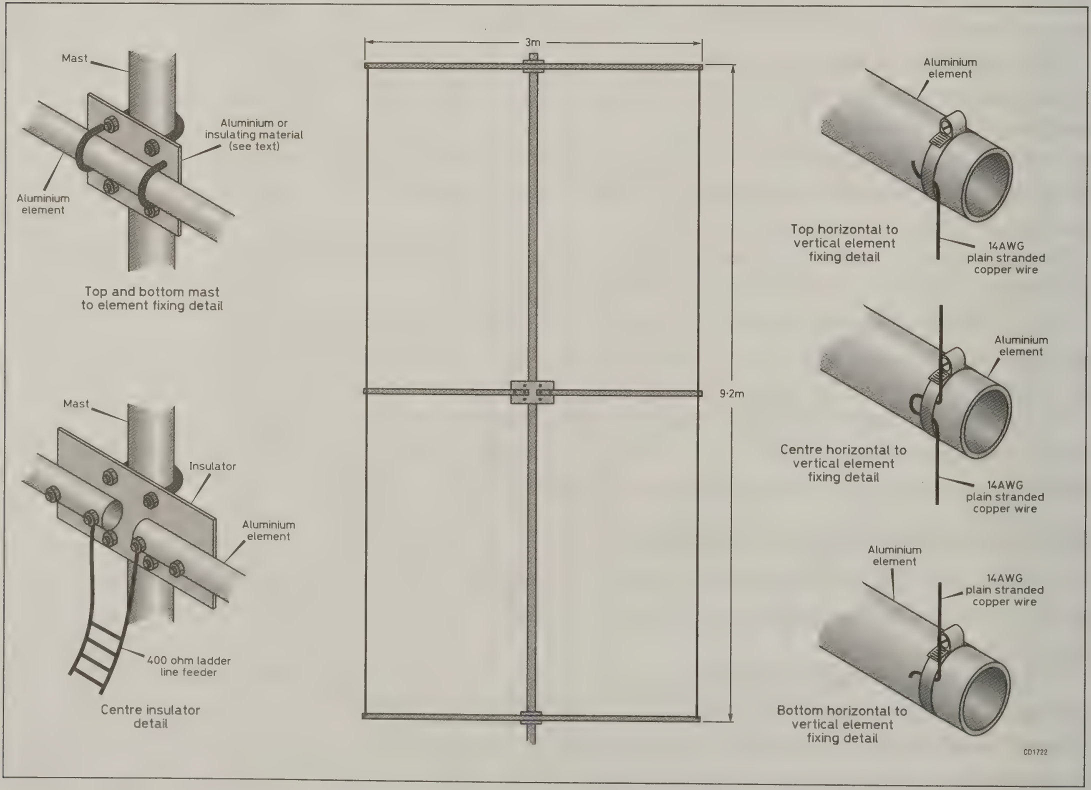

Mast
Aluminium or insulating material (see text)
Aluminium element
Top and bottom mast to element fixing detail
3m
9·2m
Aluminium element
Top horizontal to vertical element fixing detail
14AWG plain stranded copper wire
Aluminium element
Centre horizontal to vertical element fixing detail
14AWG plain stranded copper wire
Mast
Insulator
Aluminium element
400 ohm ladder line feeder
Centre insulator detail
Aluminium element
14AWG plain stranded copper wire
Bottom horizontal to vertical element fixing detail
CD1722

Fig 8.16: The G3LDO 14 - 28MHz skeleton slot antenna. The elements are fixed to the mast and the whole mast is rotated. The wire elements are fixed to the horizontal elements with hose clips. The centre insulator, as shown, is home made but a commercial one would be suitable.

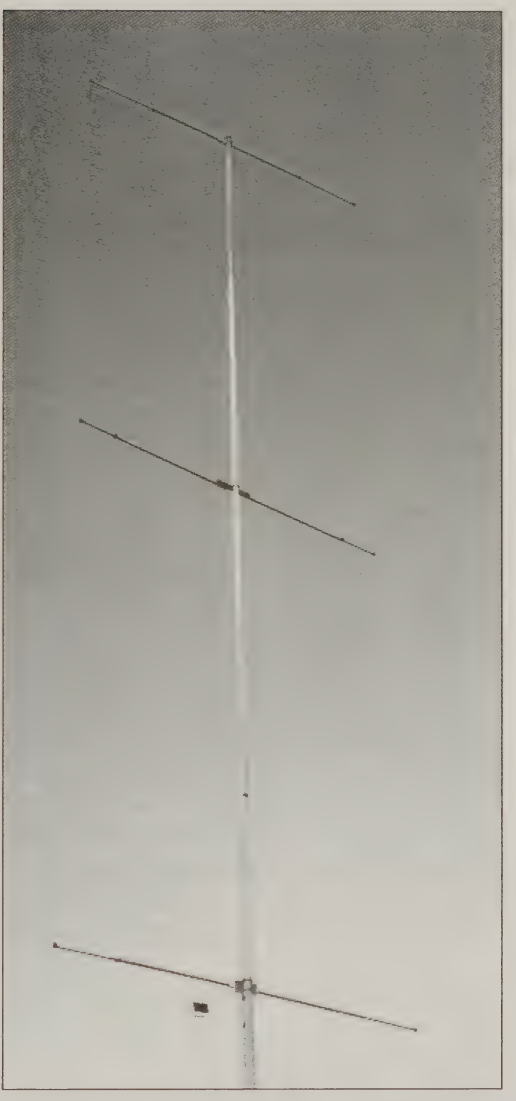


Fig 8.17: The G3LDO multiiband Skeleton slot antenna for 14 to 28MHz.

The centres of the upper and lower elements can be fixed directly to a metal mast using an aluminium plate and U-bolts as shown in Fig 8.16. The dimension of this antenna regarding aluminium tube/wire diameters and length are not critical

The antenna requires a balanced feed and is fed with 450-ohm slotted line feeder, although the feeder impedance is not critical. The feeder should be fixed on stand-off insulators about 6in from the mast until clear of the lower element to prevent them blowing about in the wind and affecting the impedance, although this was not done in the antenna shown in **Fig 8.17**.

An ATU with a balanced output is required. I used a conventional Z Match with the two sets of balanced outputs, one ostensibly for the higher HF frequencies and the other for the lower ones. In practice the lower frequency output worked best for all frequencies. In practice the antenna can be fed with any of the ATUs described in Chapter 4.

This skeleton slot was built to the size specified by Bill Capstick and these dimensions seem near optimum for the five higher HF frequency bands. While the DX performance of this antenna is good up to 30MHz it deteriorates at frequencies higher than this.

On 21, 24 and 28MHz the antenna performed very well, particularly when conditions were marginal. On 21MHz DX stations consistently gave two S-points better than received when using a linear. Early morning contacts with the Pacific had noticeable echoes, probably due to the bi-directional nature of the antenna.

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[3] 'Roof-space dual band magnetic loop', Eric Sandys, GI2FHN, 'Technical Topics' column, *Radcom* February, 1993.
[4] 'Skeleton Slot Aerials', B.Sykes, *RSGB Bulletin* (forerunner of the RSGB's *Radcom*) January 1953.
[5] 'The HF Skeleton Slot Antenna', Bill Capstick, *Radcom* June 1996.

9

Hardware and construction methods

The main difficulties encountered by newcomers (and some old-timers) when constructing an antenna is acquiring or constructing antenna fittings. This chapter describes, for example, the construction of boom element extensions and quad spiders that you can make without the use of any specialised tools. A hacksaw, a variety of screwdrivers, spanners, a selection of files and an electric drill are all that is required. Use protective gloves when sawing metal - some of the edges can be quite sharp.

MATERIALS

Antenna wire

Most HF wire antennas are constructed from copper wire, which has a low electrical resistance and is relatively easy to work. In most cases, the selection of wire for an antenna will be based primarily on the antenna under construction. 14SWG or 16SWG hard-drawn copper wire is the material of choice for long resonant antennas (80 or 160m) where significant stretch cannot be tolerated. Care is required when handling this wire because it has a tendency to spiral when it is unrolled. Make sure that kinks do not develop; wire has a far greater tendency to break at a kink.

The use of hard drawn copper wire is even more important if you are feeding a centre-fed wire dipole with heavy coax such as RG213, where the antenna has to support the considerable weight of the feeder. A more satisfactory arrangement is to use twin line feeder, as is described in Chapter 2.

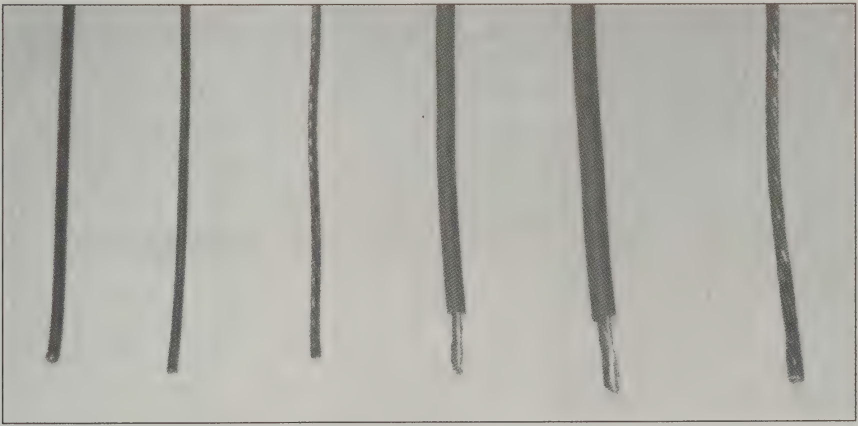


Fig 9.1: Various types of antenna wire. From the left to right, (1) 14SWG hard drawn single strand, (2) 16SWG hard drawn single strand, (3) 14SWG multi-strand, (4) Plastic covered 1.5mm multi-strand, (5) Plastic covered 2mm multi-strand, (6) multi-strand Flexweave antenna wire. (wire samples supplied by W H Westlake Electronics)

For the upper HF bands 14 or 16SWG soft drawn wire may be suitable. For wire beams, insulated 14 to 16SWG multi-strand flexible tinned copper wire is my first choice. Wire having an enamel coating is also useful and preferable to bare wire, since the coating resists oxidation and corrosion.

The RF resistance of copper wire increases as the size of the wire decreases. However, in most types of antennas that are commonly constructed of wire (even quite thin wire), the radiation resistance will be much higher than the RF resistance, and the efficiency of the antenna will still be quite good. Wire sizes as small as 0.3mm have been used quite successfully in the construction of 'invisible' antennas in areas where conventional antennas cannot be erected. Antennas having a high radiation resistance, such as the large wire loop described in Chapter 8, are more suitable for using thin wire.

Most antenna material dealers sell various types of antenna wire as shown in **Fig 9.1**.

A cheap source of hard-drawn material is outdoor telephone twin, insulated wire, used (in the UK) to distribute underground cable to customers via a telegraph pole. The formula used by BT (British Telecom) adds one percent cadmium to the copper, which increases its tensile strength by 50%.

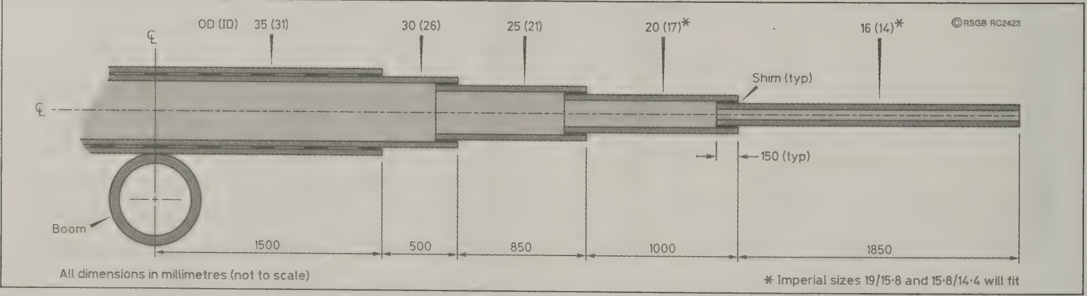
Aluminium tubing

Some of the beam antennas described in this book are constructed from aluminium tubing. Self-supporting horizontal HF beam elements require careful mechanical design to arrive at the best compromise between storm survival, sag and weight. This is done by 'tapering' the elements, ie assembling the elements from telescoping tubes, thick in the centre and thinner, in several steps, towards the tips as shown in **Fig 9.2**. G4LQI [1] has investigated the availability of aluminium tubing and what follows is the result of his work.

The most common range of American tubing comes in OD steps of 1/8in (3.18mm), and with a wall thickness of 0.058in (1.47mm). This means that each size neatly slides into the next larger size.

British amateurs who have tried to copy proven American designs have found that this could not be done with alloy tubing available in the UK. The only tubing sizes easily obtainable in the UK are Imperial, regardless whether designated in inches or millimetres. They come in outside diameters steps of 1/8in (3.18mm) but with a wall thickness of 0.064in (1.63mm), so the next smaller size does not fit into the larger one. This means that the smallest taper step is 1/4in (6.35mm), requiring the filling of the 1.55mm gap with aluminium shims. This method of construction is described later.

Fig 9.2: A 14MHz reflector designed to survive wind speeds of up to 159km/h, sagging 16cm and weighing 5.6kg



American-size tubing is perfect; each size just fits into the 1/8in larger size. With the imperial sizes available in the UK, the minimum step is ¼in.

Aluminium tubing is also available from scrap yards. However, with the exception of scaffolding poles, aluminium tubing is the scarcest material to find. This is because there are not many commodities in our society using this material, and where it is available it only comes in one-off items such as tent poles. Aluminium is normally stored in skips at a scrap metal yard so any aluminium tubing that arrives is quickly chopped up into short lengths.

There is a further type of material called duralumin, commonly used for aircraft construction and boat masts. It has the advantage of being lighter and stronger than aluminium but is more brittle. In fact almost all aluminium tube is an alloy of some sort because pure aluminium is rather malleable.

Aluminium or duralumin tubing is useful for making lightweight masts and antenna booms. The most common size is 50mm diameter with a 2mm wall thickness.

Shorter lengths of aluminium tube can be joined together using extension sleeves. You can make your own extension sleeves as shown in **Fig 9.3**. This is done with a short section of the same or similar (slightly larger) diameter tubing, which is sawn longitudinally down one side. The coupling slot is prised apart using screwdrivers and forced over one end of the section of tubing to be extended. The extension tube can then be forced into the other side of the coupling and the whole lot clamped together with jubilee clips. If the joint is required to handle torque then more than three jubilee clips may be required; or holes can be drilled through the joint and self tapping screws inserted to secure it.

Aluminium scaffolding poles are useful for masts and booms of larger HF beams. This material is thick walled (around 4mm thick) and is

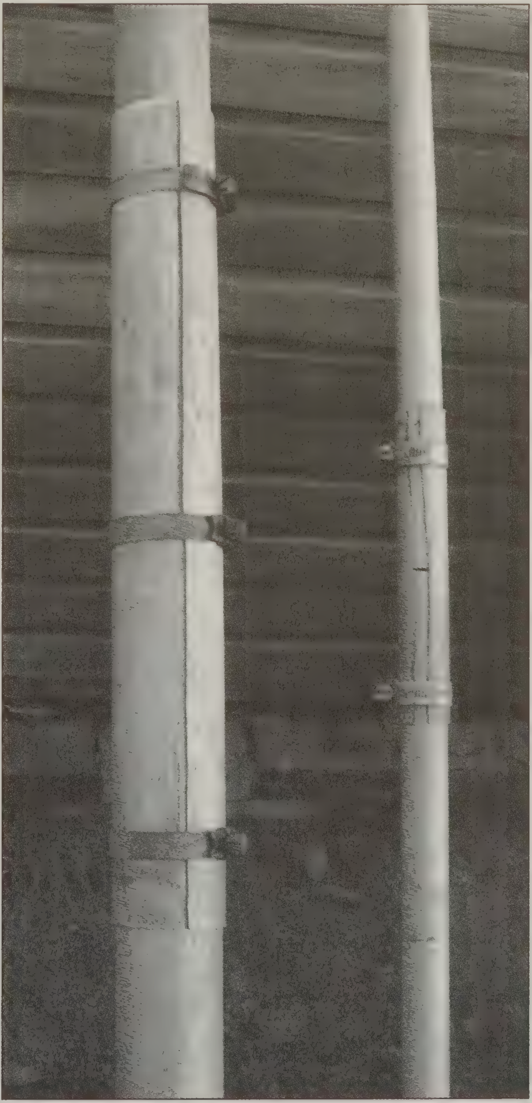


Fig 9.3: Method of joining lightweight tubes of equal diameters.

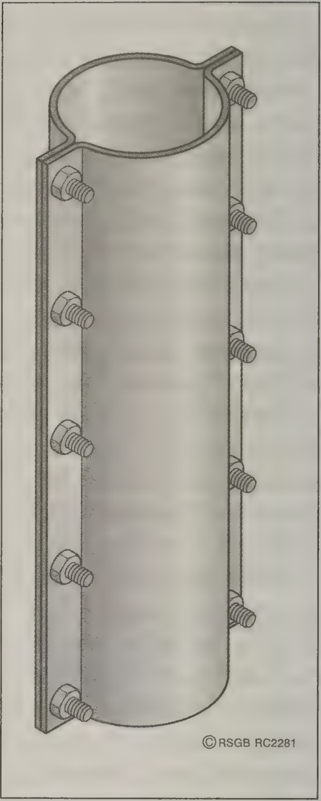


Fig 9.4: Two-piece steel sleeves of the type used to join scaffolding tubes together.

very strong. The diameter of this material varies but is around 50mm (just under 2in). Heavy weight extension sleeves are available, see **Fig 9.4**. Its use in the construction of a fold-over mast is described in Chapter 10.

Steel tubing

Steel tubing is an excellent material for constructing antenna masts and its use is described in Chapter 10.

Copper tubing

Copper has a very good conductivity but is rather heavy so is not suitable for large HF antennas. However it can be used for the construction of small compact HF antennas, VHF antennas and mobile HF antennas. A further advantage of copper for the antenna constructor is that there is a good selection of couplings available. Copper tubing is also relatively plentiful in DIY stores. In the UK the most common copper tubing diameters available are 16 and 22mm.

Aluminium plates

Aluminium plates are particularly useful for making mast-to-boom and boom-to-element fixings. I find that this material is fairly common at junk yards. An example of a mast to boom clamp constructed using exhaust pipe clamps and 5mm thick aluminium plate is shown in **Fig 9.5**.

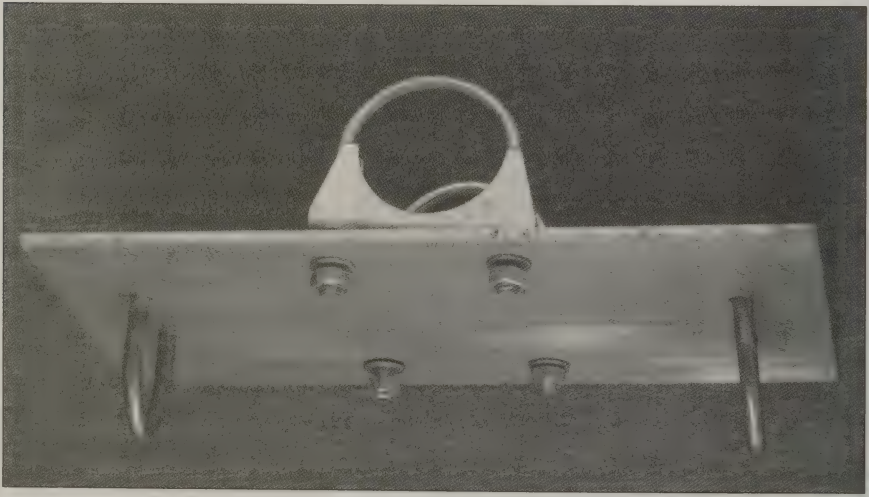


Fig 9.5: Example of a mast to boom clamp constructed using exhaust pipe clamps and 5mm thick aluminium plate.

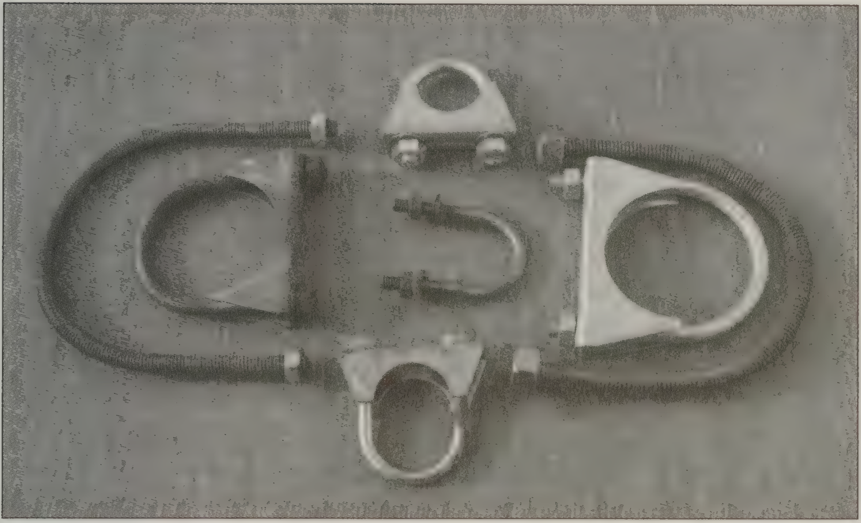


Fig 9.6: Assortment of exhaust pipe clamps suitable for antenna construction. Also shown are two large diameter U-bolts made from 8 and 9mm (1/4 and 5/16 in) threaded stock.

Exhaust pipe clamps

These clamps (known as muffler clamps in the USA) are used to construct boom-to-mast and element-to-boom fittings. They can also be used to fit angle stock to booms when constructing Quad spiders or X beam element supports. The clamp comprises a U-bolt and a metal former whose purpose is to fit a section of tubing to a flat surface. They come in a range of sizes to fit tubing from 1 to 2½ inches (25mm to 64mm). Unfortunately, there seems to be no standardisation of U-bolt thread types so you have to be careful not to loose the U-bolt nuts in the grass while working on the antenna.

You can make large diameter U-bolts from 8 or 9mm (1/4 or 5/16in) threaded stock. This material is available in various diameters from DIY stores and it comes with a packet of appropriately sized nuts. The material is cut to the required length and one end is clamped in a vice (run two or three nuts onto the vice clamped end to prevent damage to the threads). The free end is then bent so that eventually the material forms a U-shape. A short length of steel pipe can be used as a lever. It will take a bit of practice to get it right but some idea of the finished item can be seen in **Fig 9.6**.

Jubilee clips

Also known as hose clips, these really are the antenna experimenter's friend. They can be used for joining different diameter sections of elements, joining sections of mast, joining wire to metal elements, joining quad spreaders to angle stock - the list is endless. They are readily available at all hardware, DIY and car part stores. When used as part of an outdoor antenna structure always coat them with a film of grease to prevent corrosion. Never use paint or varnish because this will make it impossible to remove and also make it unusable for further construction projects.

Aluminium angle material

This material is most useful for fixing elements or element supports to a mast or boom as described above. When used with an exhaust clamp it makes a very

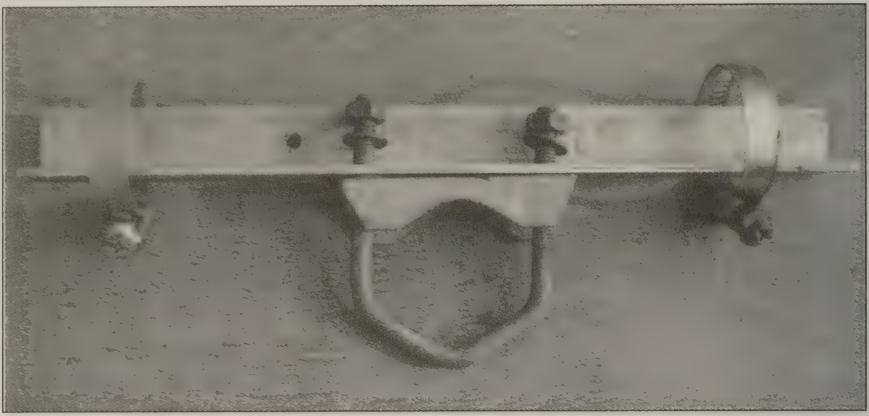


Fig 9.7: Example of an element to boom clamp constructed using exhaust pipe clamps and aluminium angle stock.

strong yet simple fitting. It can also be used to fit aluminium elements to a boom. **Fig 9.7** illustrates this method.

Insulators

The best insulators for antenna use are made of glass or glazed porcelain. Depending on the type of wire antenna the insulator may also have to be capable of taking the strain of the antenna wire, supporting cable and the feeder.

Insulators can be constructed from plastic tubing providing that it is strong enough. One example of such material is the plastic pipe used for domestic high-pressure water systems and can be bought at DIY stores. Alternatively there always seem so be a lot of off-cuts around on building sites. An even better material is the pipe used for upgrading gas supply pipes. This is a yellow pipe that is inserted into old steel or cast iron gas mains during the upgrade.

Spreaders for wire beams

Ideally, the element support spreaders for wire beams should be made from tapered fibre-glass rods. These are expensive and are rather hard to come by, but they do have the outstanding advantage of being strong and durable. A cheaper and a much more easily obtained material is bamboo. It comes in the form of garden canes, the sort normally found in garden centres.

Bamboo canes do need weather protection if they are to last any time at all. The favourite method is to treat them with a couple of coats of outdoor shellac

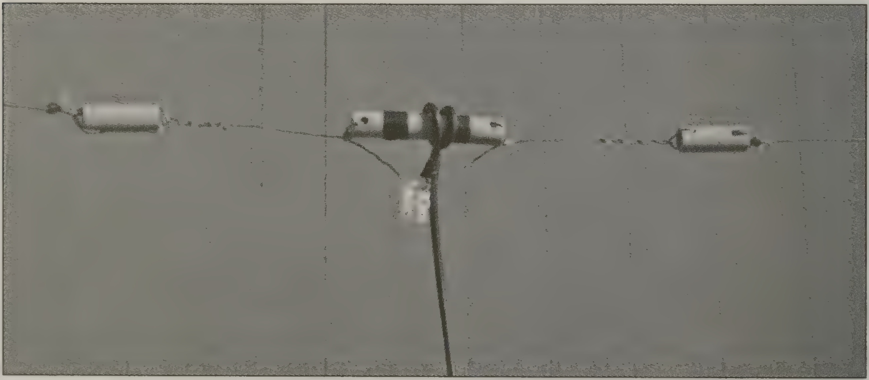


Fig 9.8: Example of the use of home made insulators to make centre and end insulators for a lightweight dipole antenna.

or varnish, which should result in them lasting more than a year or so. There are various wood preservatives available these days and any one of these products should prolong the life of cane spreaders.

W6SAI [2] recommends weatherproofing canes with fibreglass. This is done by wrapping the canes with 3inch wide fibreglass cloth in a spiral fashion and temporally fixing it in place with rubber bands. The cloth is then coated with activated resin and left to harden. An additional coating of resin can be applied to improve strength and durability.

This treatment will produce cane supports that will last a long time but fibreglass resin can be messy when being applied. Four bamboo poles are required for each quad loop and these should be clean, straight and free of splits and cracks between the rings.

Ropes and cords

Ropes suitable for guying or supporting antennas purposes are best chosen from one of the man-made fibres, such as polypropylene or Terylene. These materials, while having good strength, do not rot and are impervious to oil and the hazards of weather. Like their steel counterparts, they follow the traditional form, consisting of three strands laid spirally together. When purchasing, remember that the old method of specifying size was by quoting the circumference and not the diameter. Now that metric units are established you may find the rope size given as a diameter in millimetres. A popular size approximates to 0.75in circumference; this fits other useful rigging items such as pulley blocks, thimbles and rigging screws.

These man-made fibres, being plastic, are susceptible to heat, which can cause damage if chafing occurs, but this is a most useful property as it greatly assists cutting and sealing. For this, you can use either a chisel-pointed soldering iron or a naked flame, but try not to use a knife as the lays and the individual filaments will spring apart, leaving you with something akin to a very small bunch of flowers! Choose the place for cutting, lay the rope flat on a hard surface, such as a piece of sheet-metal offcut, and press the hot chisel bit down on the rope with a steady pressure until it parts. This procedure will most probably have sealed off the two ends.

The same effect can be achieved with a pencil-thin gas flame, where you hold the rope in both hands and offer the selected spot to the flame while keeping a gentle pull. When it parts, the two ends will be molten, and a quick squeeze with pliers to compact them; do not use fingers, as the molten plastic can stick to them and give a bad burn. Alternatively, rotate each end in turn in the flame until a blob forms, and cool it by blowing..

Should you decide to make a super job by then splicing the rope end into an insulator, thimble or rigging screw, you should unlay each of the strands and seal each in turn, just as you did the rope itself. Splicing these ropes need not be as daunting as it sounds, and it provides an immensely strong fixing that will last for years and looks good too.

A spliced rope retains 90% of its initial strength, whereas, if knotted, it is reduced to only 50% although this is not normally an issue for supporting a wire antenna.

J M Gale, G3JMG, has written much more about this topic, see [3].

Pulleys

Several types of pulley are readily available at almost any hardware store. Among these are small galvanised pulleys designed for awnings and several styles and sizes of clothesline pulleys. Heavier and stronger pulleys, used in marine work, are very suitable for antenna installations. The factors that determine how much stress a pulley will handle include the diameter of the shaft, how securely the shaft is fitted into the sheath and the size and material that the frame is made of. Another important factor to be considered in the selection of a pulley is its ability to resist corrosion. Most good-quality clothesline pulleys are made of alloys that do not corrode readily. Since they are designed to carry at least 50ft of line loaded with wet clothing in strong winds, they should be adequate for normal spans of 100 to 150ft between stable supports. Chose a pulley to suit the line. The worse situation that can happen with a pulley is when a thin line gets trapped between the pulley wheel and the sheath.

Specialised antenna fittings

There are several fittings that are used by the TV antenna industry that can be pressed into amateur radio antenna service, and a number of these are shown in **Fig 9.9**. These items are normally used for fixing a TV antenna to a mast. Some of the larger ones can be used for fixing elements to booms of small HF antennas or VHF antennas to masts as shown in **Fig 9.10**.

SCRAPYARD AS A SOURCE OF MATERIALS

A scrap metal yard can be a good source of antenna material. Antenna construction and experimenting costs can be reduced considerably by using materials from these sources because they are sold at scrap weight values. If you are really into antenna building and experimenting, it pays to visit the scrap metal yard regularly because specific items are rarely found during one visit. The policy of

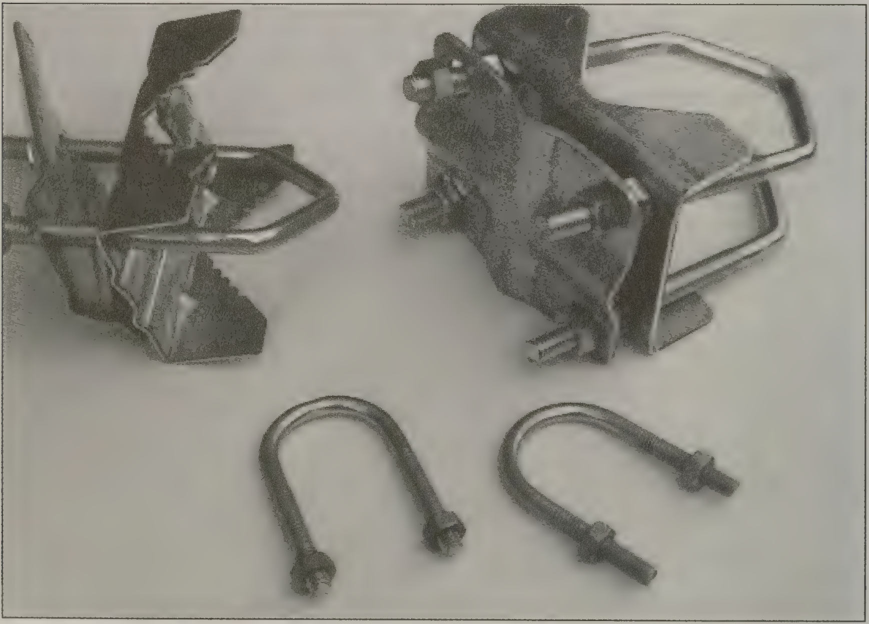


Fig 9.9: Selection of commercial antenna fittings.

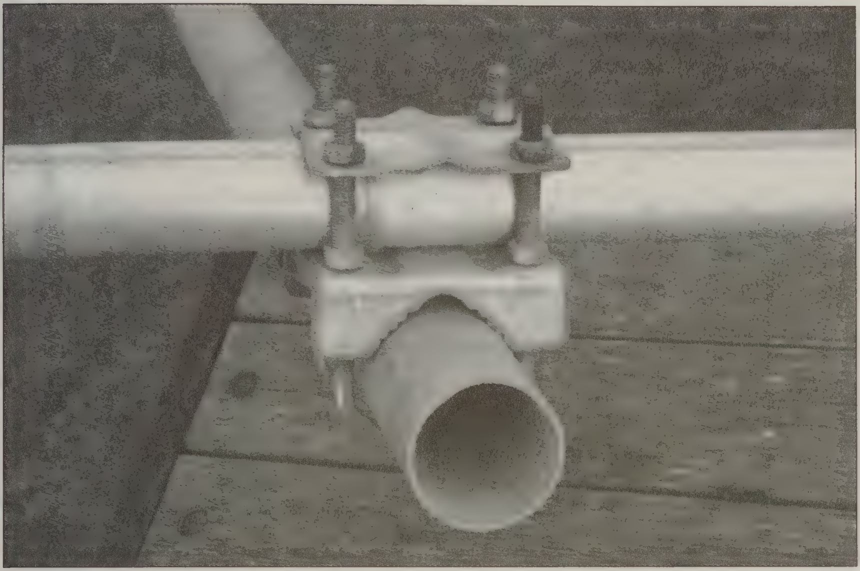


Fig 9.10: A TV antenna fitting used to secure the boom of a HF antenna to a 2in mast.

some scrap metal dealers is to reduce tubing and pipes to short lengths when it arrives on site to make it more manageable. Others keep long lengths because they consider it as a more marketable commodity in this form.

The best scrap metal yards are those located near an industrial estate. These contain a much more useful selection of material for antenna constructor. Materials obtainable from scrap metal yards, useful for antenna work construction, are listed below:

- Copper and aluminium tubing (for elements and booms)
- Aluminium angle stock (quad, hexbeam and Double-D antenna spreaders)
- Aluminium plate (couplers for joining elements to booms and booms to masts, see Fig 9.5)
- Paxolin, Bakelite or plastic sheet (Insulators)
- Antenna wire can sometimes be found in scrap yards. However, scrap electrical wire is usually heavily insulated and therefore too heavy for antenna elements but is fine for radials.
- Steel tubing (for antenna masts)
- Steel casing (for mast foundations)
- Steel angle material (for ginpoles, clamps and guy rope anchors)
- Electric motors and gear-boxes (for rotators)

ANTENNA CONSTRUCTION TECHNIQUES

Wire antennas

Wire antennas should preferably be made with unbroken lengths of wire. In instances where this is not feasible, wire sections should be spliced. The insulation or corrosion should be removed for a distance of about 100mm from the end of each section and the wire cleaned until the copper underneath is bright. The ends of the wire should be wrapped tightly around each other.

Most authorities advise that such a joint should not be soldered on the grounds that it anneals the copper. However, if you are using stranded soft-drawn copper wire then a soldered joint can be considered, particularly if you are located in an area where corrosion is a problem, such as a seaside location.

To solder a joint the crevices formed by the wire splice should be smeared with solder flux. A large wattage soldering iron will be required to melt solder when working outdoors. The joint should be heated sufficiently so the solder flows freely into the joint. After the joint has cooled it should be wiped clean with a cloth and coated with grease to prevent corrosion.

All metal antenna construction

The boom can be fixed to a tubular mast with a metal plate and car exhaust U clamps as shown earlier in Fig 9.5. Elements can be connected to booms in a similar manner.

Tapered elements can be constructed from lengths of aluminium alloy tubing with different diameters so that the lengths can be telescoped into each other. I rarely find that sections fit snugly and the ends of joining sections need to be modified as shown in **Fig 9.11**.

Additionally, if there is a relatively large difference between the two joining sections, a shim can be made from a short section of tubing, slit longitudinally. Any corrosion on any of the metal surfaces that make up the join should be removed with fine sandpaper. The surfaces are then wiped with a cloth and coated with a thin film of grease to prevent corrosion. The join is then clamped tight using a hose clamp. This method is far superior to using a nut and bolt where a new set of holes has to be drilled every time an adjustment to length is made. The hose clamp method also gives the joint a lower contact resistance.

If the antenna elements are constructed from tubing and insulated copper wire (such as the all metal quad, see Chapter 7), then a short length of the plastic insulation is stripped from the wire element extensions. These ends are then fixed with hose clamps to the end of the metal elements.

It is particularly important that these copper wire/aluminium tube joins are protected with grease to prevent corrosion. However, one authority [4] even goes as far as to state that contact between aluminium and copper should be

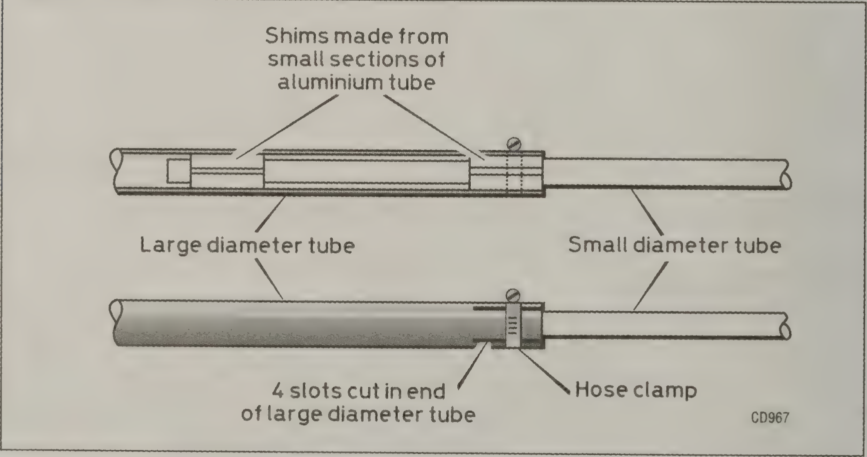

Shims made from small sections of aluminium tube
Large diameter tube
Small diameter tube
4 slots cut in end of large diameter tube
Hose clamp
CD967

Fig 9.11: Method of joining sections of aluminium tube where the tube diameters present a poor fit. (Top drawing depicts cross section of joint).

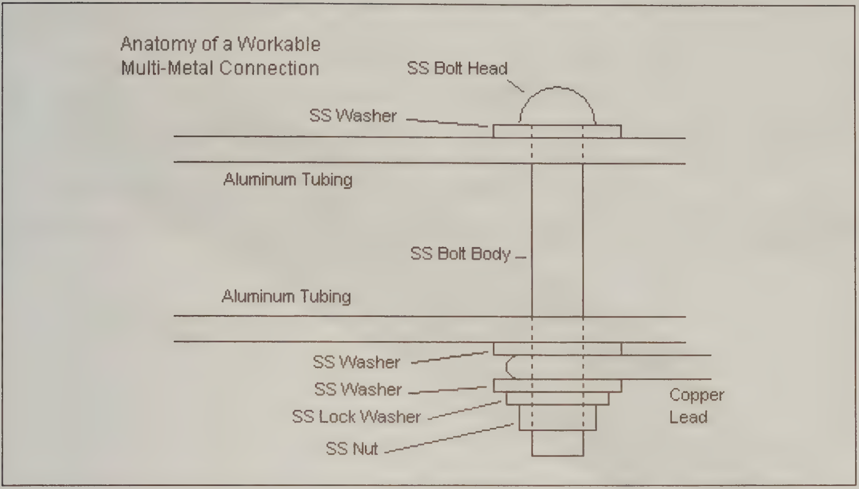


Fig 9.12: Method of connecting copper wire to aluminium tubing using stainless steel hardware.

avoided at all costs and that a small stainless steel washer should be used to provide isolation, together with stainless steel nuts and bolts as shown in **Fig 9.12**.

Wire beam supports

A fixing, which avoids damaging the ends of cane or fibreglass and aluminium wire beam element supports can be made using aluminium angle. The length of this aluminium section depends on the size and the frequency range of the antennas to be supported and for a conventional multi-band quad or Double-D a three-foot length is suitable. Two sections are required for a Double-D or four for a quad as shown in **Fig 9.13**.

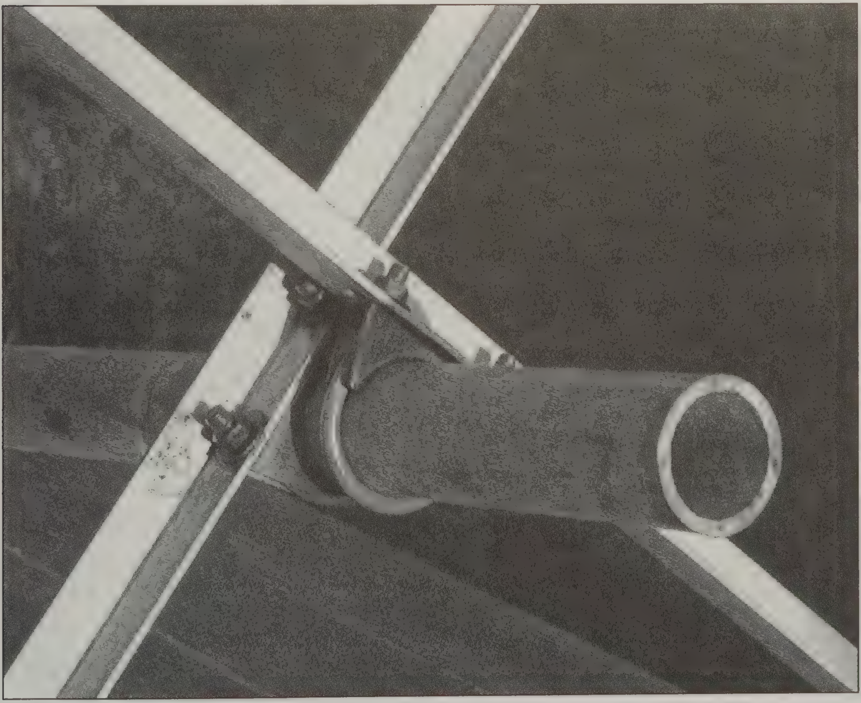
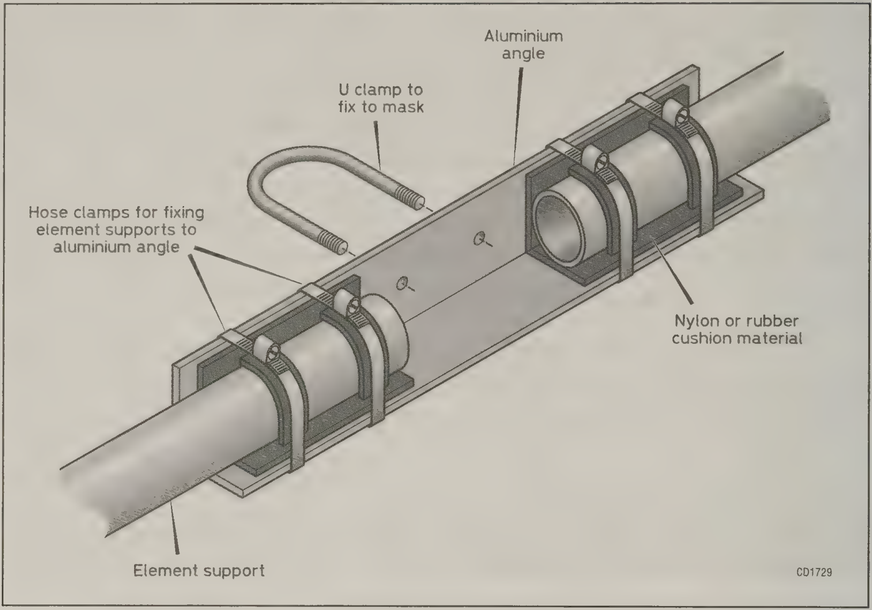


Fig 9.13: An arrangement using U bolts and aluminium angle makes a very rugged and lightweight hub for quads, Moxon rectangles and any other wire beam antennas.

Fig 9.14: Method of fixing cane or fibreglass wire beam element supports to a boom or mast. The length of the aluminium angle material and the spacing between the hose clamp supports depends on the sized of the antenna structure.


Aluminium angle
U clamp to fix to mask
Hose clamps for fixing element supports to aluminium angle
Nylon or rubber cushion material
Element support
CD1729

Two holes are drilled at the centre of each section, the distance apart will depend on the size of the mast or boom and hence the size of the U-bolts.

The canes or fibreglass rods are fixed to the ends of the aluminium angle using hose clamps as shown in **Fig 9.14**. Rubber or plastic tubing cushions can be used to prevent the clamps damaging in cane or fibreglass rod supports. This type of fitting can also be used for fixing insulated supports for coax as shown in **Fig 9.15**.

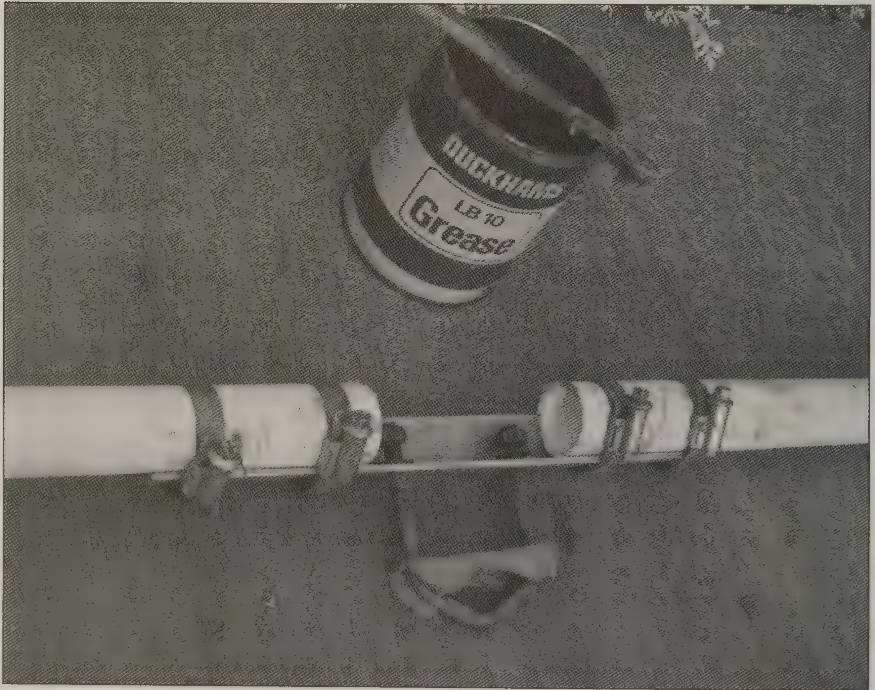


Fig 9.15: Method of fixing insulated transmission line supports to the mast. All joins will benefit from a coating of grease to prevent corrosion.

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[4] *Protection against atmospheric corrosion*, Karel Barton (John Wiley, 1976)

10

Antenna supports and masts

The main problem regarding antenna construction faced by most radio amateurs is installing the antenna high enough and safely enough to be effective. Placing a large antenna 10 or 20 metres (30 to 60 feet) into the air, with access for adjustment and tuning can be a minor civil engineering project.

In the case of a simple wire antenna, the chimney or the roof of the house or even a tree may be suitable. For a directional antenna something more elaborate may be required depending on the size of the antenna.

A further consideration is antenna accessibility. When adjusting a beam antenna for the best directivity or adjusting a matching system for the lowest SWR, access to the antenna is important. It is rare that an antenna can be constructed from an article or some plans and that its performance will be optimum straight away. Most antennas, and this includes commercial ones, have to be adjusted to give the best performance. This is where access to the antenna is important. So let us look at the advantages and disadvantages of various antenna support arrangements.

COMMERCIAL MASTS

Many radio amateurs use commercial lattice construction masts, which have a telescoping and fold-over capability. They have the advantage of having well-defined data regarding heights and wind loading, although they have a fairly high visual impact, which may be a problem in some locations. They are also fairly expensive.

A drawback to trying to adjust an antenna using these types of support is that they take some time and effort to raise and lower. Additionally, the winch cables are not designed for the continual raising and lowering normally encountered when a lot of antenna work is being done over a period of time.

TREES

If you have a tall tree in your garden, you may have a very good support for a wire antenna that does not require planning permission. As antenna supports, trees are unstable in windy conditions, except in the case of very large trees where the antenna support is well down from the top branches.

Tree supported antennas must be constructed much more sturdily than is necessary with stable supports. To this end the preferred method is to use a halyard and pulley. The use of a halyard with a mast is shown in **Fig10.1(a)**. Here the halyard end can be lashed to a bracket. When a tree is used as the support a

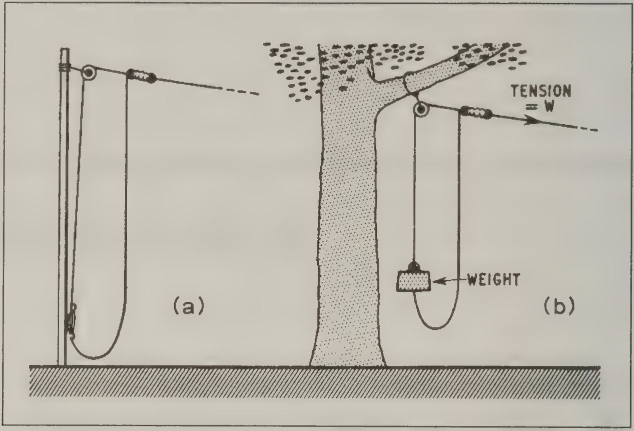


Fig10.1: Halyard connections to (a) a pole and (b) a tree. The weight is equal to the required antenna wire tension.

weight is used, see **Fig10.1(b)**, to take up the movement of the tree. The endless loop is to allow greater control of when raising and lowering the antenna.

If the point where the pulley is to be attached can be reached using a ladder then fixing it to a branch, pole or building is the easy bit. If you cannot reach the pulley fixing point then a line has to be thrown or propelled over the anchor point.

Antenna missile projector

Whether you are trying to get an antenna support over a tree branch or over the roof of a tall house you might find this missile projector useful. It is basically a catapult as shown in **Fig10.2**. A missile or weight must be used that will not cause damage or injury if things go wrong. The best object for this purpose is a squash ball or a plastic practice golf ball filled with wood filler. If you are using a tree as support a heavier weight might be in order (provided the area is clear of people and windows) to overcome the friction of the cord over the branch.

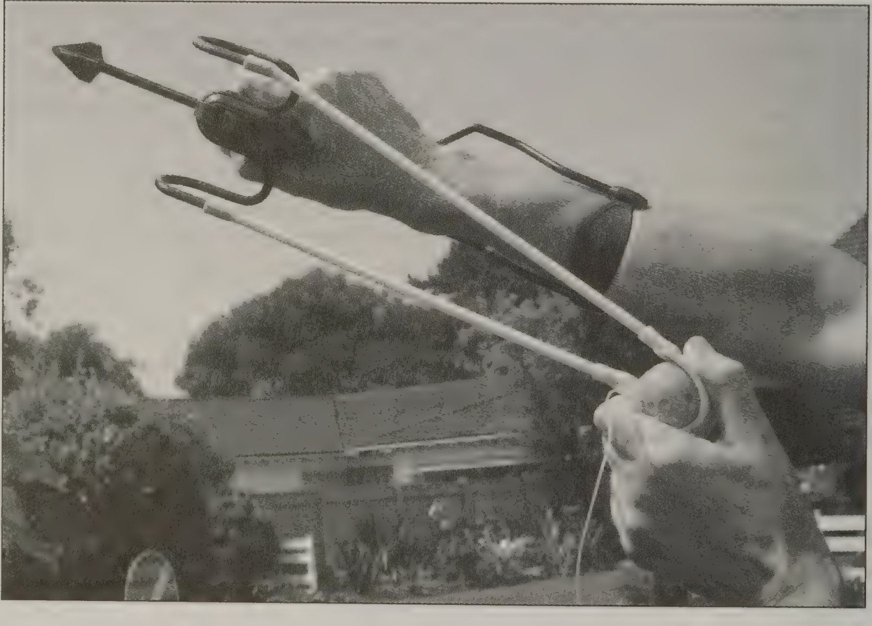


Fig10.2: An antenna support catapult launch pad. The catapult is held nearly upside down so that the line does not get caught up with anything when fired. It is advisable to gain proficiency with few practice runs in an open space before using it to secure an antenna support.

The best sort of pilot line is strimmer cord. This comes in several diameters, the heaviest for heavy-duty petrol driven strimmers and the lightest weight for electric strimmers; the latter being the most suitable for our purpose. Strimmer line is very strong and resists kinking.

The line can be stretched out straight or zigzagged left and right on the ground. If snarling of the line in a problem (due, say, to garden plants and bushes) try making a stationary reel by driving eight nails, arranged in a circle, through 20mm board. After winding the line around the circle formed by the nails, the line should reel off readily at lift-off. The board should be tilted at approximately right angles to the path of the shot.

If it is necessary to retrieve the line and start over again, the line should be drawn back very slowly; otherwise the swinging weight may wrap the line around a small branch, making retrieval impossible.

The pilot line can be used to pull a heavier line over the tree or roof. This line can then be used to haul a pulley up into the tree after the antenna halyard has been threaded through the pulley. The line that holds the pulley must be capable of withstanding considerable chafing from the branch.

A metal ring, around 70 -100mm (3 to 4in) in diameter can be used instead of a pulley. The antenna support wire is just looped through the ring. This has more friction than a pulley but it will not jam.

USING THE HOUSE AS AN ANTENNA SUPPORT

The house roof and chimney

Many houses in the UK have a chimney that can be used for an antenna support. The house chimney is usually the tallest point of the building, which has advantages discussed in Chapter 1. The further advantage of this method is that chimney-mounting brackets are easy to obtain.

The chimney of an older house, where the mortar that has weakened over the years, needs to be examined, and if necessary repointed before fitting a chimney mounted antenna.

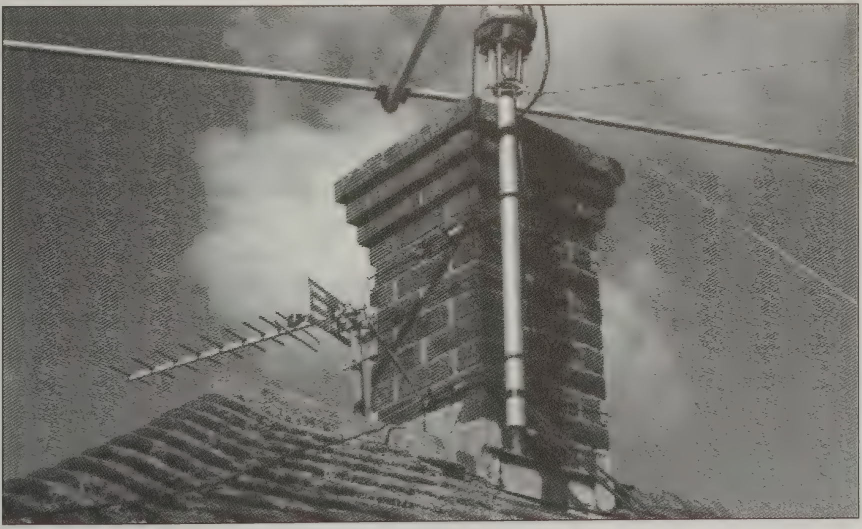


Fig10.3: Example of a chimney double lashing used to support a small HF antenna.

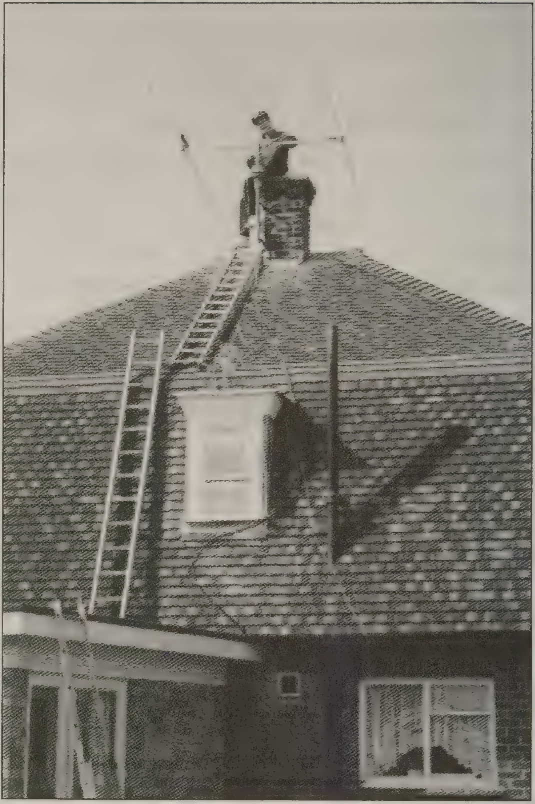


Fig 10.4: Accessing the chimney of a house using ladders. The ladder on the roof has been adapted with lugs to clip over the apex of the roof to make a crawling ladder.

The single wire lashing kits used for TV antennas are not really suitable for amateur radio antennas although these can be seen supporting some precariously tall TV antenna structures in fringe TV signal areas.

A double TV antenna chimney lashing kit will support a large VHF array or a small sized HF beam as shown in **Fig10.3**.

The disadvantage of a chimney-mounted antenna is the problem of access. If the house is fairly small, as the one shown in **Fig 10.4**, then setting up ladders to reach the chimney can be relatively simple. Don't even think of walking on the roof with out the use of a crawling ladder.

Wall mounted masts

A lightweight mast of scaffolding pole can be fixed to the house with wall brackets. Useful advice for fixing wall brackets comes from G3SEK [1] as follows:

Even a small antenna installation can generate considerable wind forces on the support structure.

Think about the directions in which the wind force could act. If the wind is pushing the bracket on to the wall, the force is spread over several bricks, and the fixing is as strong as the wall itself. If the wind is blowing parallel to the wall, and the bracket is strong enough, most kinds of wall fixings will be extremely secure against the sideways forces. The difficult situation is when the wind is blowing away from the wall and trying to pull the bolts straight out of the bricks . . . or the bricks straight out of the wall. This latter possibility is a serious one unless the wall is well built. Older houses with mortar that has weakened over the years, and bricks made before the era of factory quality control, are simply not a good prospect for a mast bolted to the wall.

Assuming your house does have reasonably sound brickwork, the aim should be to mount the top bracket as high as possible, to reduce the wind forces but always leave at least three courses of bricks between the ones you drill and the

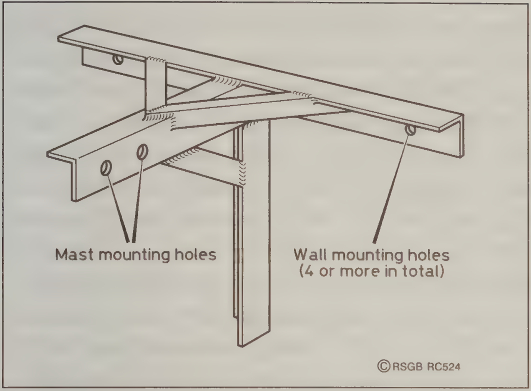


Fig10.5: A typical well-braced wall bracket

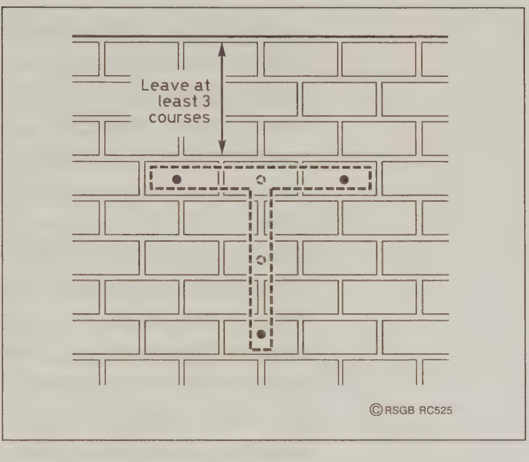


Fig10.6: Typical drilling pattern for fixing a wall bracket. Patterns may vary, but always drill into the centres of the bricks.

top of the wall. Also leave plenty of sideways clearance from upstairs window openings, which considerably weaken the brickwork. Obviously the best place to mount the top bracket is quite high on a gable end wall, to shorten the unsupported length of mast and reduce the wind forces.

The bracket itself is important. A cheap, poorly made wall bracket, intended for UHF TV antennas, is unsuitable. Go to an amateur radio dealer and get something substantial and well made, and preferably galvanised. A suitable bracket will look something like **Fig 10.5**, with a T-shaped piece that bolts to the wall and a well-braced arm for fixing the mast. All the component parts should be solidly double-seam welded, not just 'tacked' together. Typically there will be two or more bolt holes in the horizontal member of the T, and one or two more in the vertical member. The top row of fixings will bear almost the entire load, and **Fig10.6** shows a typical drilling pattern.

To fix the bracket, you must use some kind of expanding wall anchor. These come in several kinds, but they all work by expanding outwards and gripping the sides of the holes. The traditional 'Rawlbolts' are best, which can give a very secure fixing. There are other anchor methods. The 'DIY' fixing using large plastic wall plugs and 'coach bolts' are not recommended.

This is a safety-critical application, so spend some money on properly engineered fixings that are designed to work together as a system, and follow the manufacturer's instructions exactly.

The holes for the 'Rawlbolt' anchors should be drilled in the centre of the brick as shown in Fig 10.6. The optimum size for ordinary brickwork is M10, which requires a 16mm diameter hole. Three or four of these should be more than adequate to withstand the wind forces envisaged - but only if they are installed correctly.

Choose a sound set of bricks for drilling, free from any hairline cracks. If necessary, be prepared to move the mast a little from its planned location. Drill into the exact centre of each brick, not near the edges, and never into mortar. If necessary, make new mounting holes in the bracket to suit your own brickwork. The holes in the brackets should be 10mm diameter for M10 [note 1] bolts, with some extra clearance to help the bolts line up. Hold the bracket to the wall, level it with a spirit level and mark the centres of the holes. Begin drilling with a small masonry bit. Before you use the electric drill, place the point of the bit exactly on your drilling mark and tap gently with a hammer to chip out a small dimple. This will prevent the point from wandering when you start drilling. If you're using a hammer-drill, start without the hammer action until you've made a deep enough hole to prevent the bit from wandering. Do the same at each change of bit as you open out the holes gradually, using progressively larger sizes. Use patience rather than brute force, and you're more likely to make good cylindrical holes, square to the wall and exactly where you want them. It's also kinder to the electric drill; and above all it's much safer for you on the ladder.

The final holes must be exactly the right diameter as specified by the manufacturer. For example, the hole for an M10 Rawlbolt must be exactly 16mm diameter. This is very important because the entire strength of any type of wall fixing comes from the contact of the anchor sleeve against the inside of the hole. The sleeve should be a gentle tap fit, so that when the bolt is tightened the anchor will immediately start to grip hard.

Tap the anchor sleeve into place, just below the surface of the wall, so that when the bracket is bolted on it contacts the wall and not sitting on the end of the sleeve. Do this without the bolt inserted, and then fit the bracket. Leave the bolts slightly loose, level the bracket, and then tighten them. The tricky part is to tighten the bolts to the correct torque - enough to expand the anchor sleeve and develop the fixing strength, but not so much that it splits the brick and ruins the whole fixing.

Although G3SEK uses Rawlbolts, he notes that they can split the bricks if overtightened. You might consider alternative types, such as the Fischer bolts which use a softer plastic sleeve to grip the inside of the hole. In any case, use the type of anchor with a free bolt, which screws in, and not the type with a stud that takes a nut.

If your house is built using modern bricks that have holes right through the middle, conventional expanding anchors are no use, and you'll need to investigate other systems. Wall anchors using a chemical adhesive fixing system are also available, and have the advantage of not stressing the bricks at all, while having higher claimed strengths than conventional expanding anchors. They can also be used for fixing into hollow bricks, but the

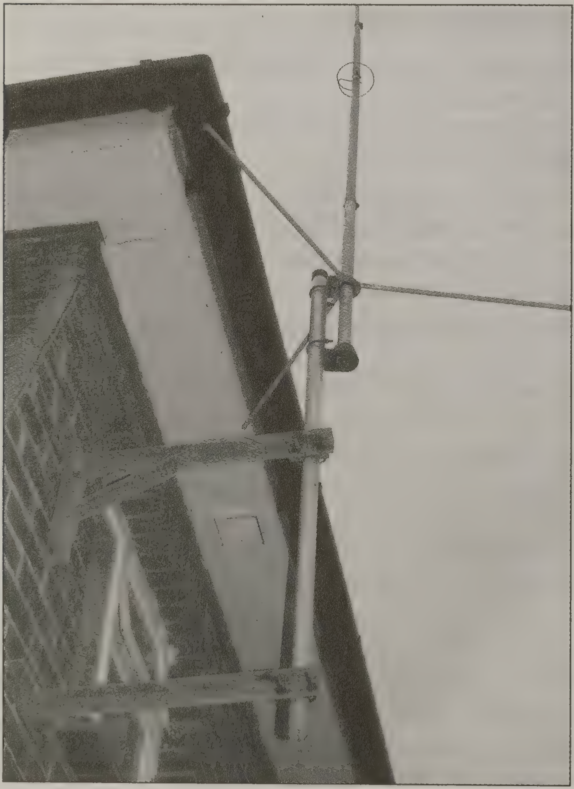


Fig 10.7: Wall brackets used to support a VHF antenna clear of an overhanging roof. This structure would support a small HF vertical antenna.

strength of the bricks themselves may become a factor. As with any adhesive bonding system, success depends on careful preparation and following the instructions exactly. One suggestion when using conventional Rawlbolts in ordinary brickwork is to use epoxy resin as well, to try and obtain the best of both worlds.

If you are fixing to a gable end wall, yet another possibility is to drill right through the whole wall and into the loft space, and then use long bolts or studs to secure the bracket to a steel plate that spreads the load over the inside wall.

The lower bracket is much simpler, because it bears much less load than the upper one. Its main purpose is to steady the mast and prevent it from bowing below the upper bracket. Mark out and drill for the lower bracket after fixing the upper one, lining them up with a plumb line. The bottom of the mast should also be fixed to prevent it from moving sideways. An example of a wall bracket installation is shown in **Fig 10.7**. Because this installation is small the brackets are placed close together. The brackets require placing further apart for a larger installation.

In the longer term, wall anchors can work loose owing to either frost or thermal expansion/contraction cycles, and then the wind will work on them further. Check the fixings every spring and autumn.

If you are intending to mount a commercial mast or antenna against the wall, obtain specific advice from the manufacturer and follow it exactly.

FOLD OVER MASTS

Commercial antenna masts were discussed at the beginning of this chapter. What follows now is the description of fold-over masts that you can construct and are easy to raise and lower. The main advantage of this type of mast design is that it makes antenna adjustment so much easier. A further advantage is that if you are concerned about your beam antenna in severe gale you can quickly fold it over if such an event is forecast.

An example of lightweight fold-over mast is shown in **Fig 10.8**. This mast was constructed by the club members of the Whangaparaoa radio club in New Zealand many years ago and it supported a three-band quad. The interesting aspect of this arrangement is that the whole mast held in place with

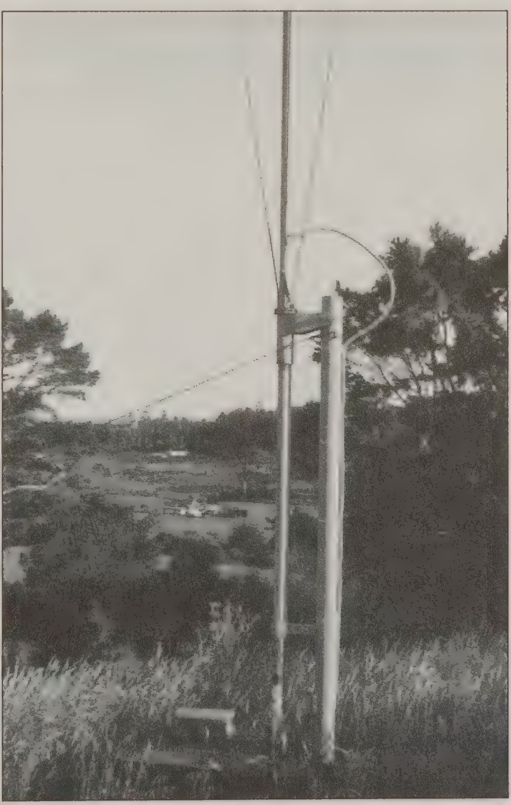


Fig 10.8: A light weight fold-over rotatable mast.

a sleeve, which is attached by a clevis to the fulcrum point. This allows the mast to be rotated inside the sleeve, either mechanically or by using a home-made rotating mechanism located at the base of the antenna shown in Fig 10.8. I don't have any details of the design but the ones that follow are very similar and the construction details are included.

Counter weighted fold-over mast

I base most of my fold over masts on one described by Alfred W Hubbard ,K0OHM [2]. It was designed to support a 3-element tri-band beam and a rotator at a height of 18 metres (60ft). All the sections of the steel tubing mast were welded together. It was partially counterweighted by filling the lower half of the tilt-over section with concrete! A winch was used to manage the remaining 160kg (350lb) top load.

I have built several of these masts. The largest was 18metre (60ft) high and supported an all metal quad. The mast and payload should not be fully counterweighted. A top weight imbalance of around 45kg (100lbs), controlled with a winch enabled the momentum of the structure to be more easily managed.

Medium-size 40 ft fold over steel mast

The following is a more detailed description of a smaller version of the K0OHM mast. This design is for a 12metre (40ft) mast but it can be scaled up or down depending on the size of the mast you require.

This mast is counterweighted with approximately 15kg (30lb) of top weight so a winch is not required. It takes about 15 seconds to raise the antenna mast into the vertical position. The mast is relatively lightweight; the top third of its length is 5cm (2in) diameter aluminium tubing. The lower section is made from 75mm and 82mm steel tubing. The sections of steel tubing that make up the mast are telescoped into each other for about 30cm (12in) and secured by bolts and nuts. This allows the mast to be assembled, modified or repositioned much more easily than if the section was welded.

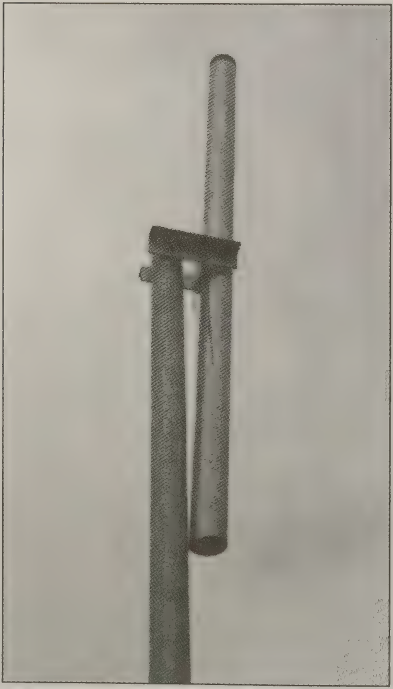


Fig 10.9: Fold-over mechanism comprising a 90mm (3½in) section of pipe with two short lengths of angle iron welded to it to make a clevis and thrust bearing.

The fixed vertical section of the mast is made from 90mm (3½in) thick-wall steel pipe with a 22mm hole drilled at the top end to take the pivotal bolt. The lower end is fitted into a casing foundation base. This base comprises a section of casing fixed in the ground with a concrete foundation. The gap between the mast and the casing can be filled with sand or pebbles. The internal casing diameter should be around 5cm (2in) greater in diameter than the vertical section of the mast.

The tilt-over mast is fixed to the vertical support mast using a 90mm (3½in) section of pipe, which have two short lengths of

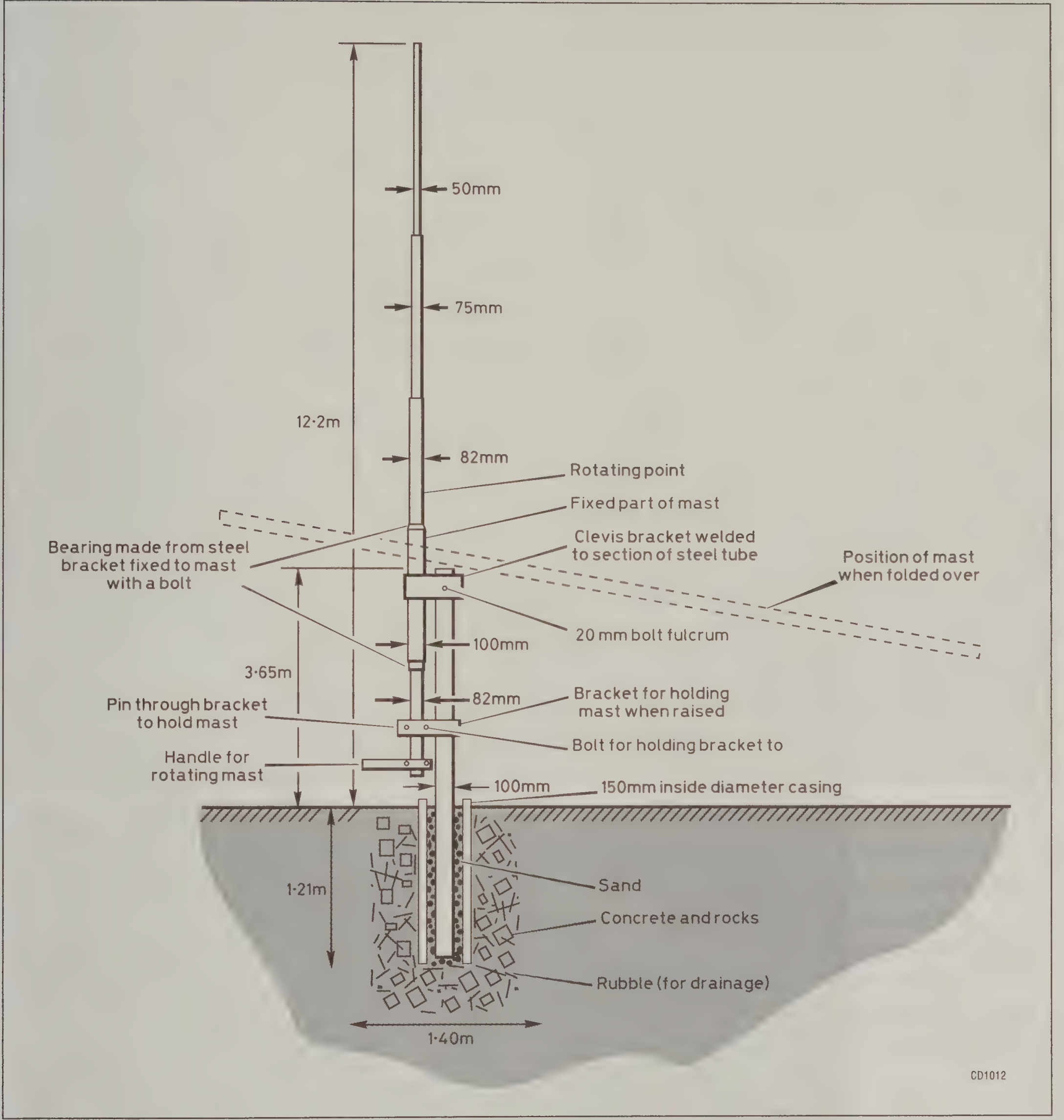

50mm
75mm
12·2m
82mm
Rotating point
Fixed part of mast
Bearing made from steel bracket fixed to mast with a bolt
Clevis bracket welded to section of steel tube
Position of mast when folded over
20 mm bolt fulcrum
100mm
3·65m
Pin through bracket to hold mast
82mm
Bracket for holding mast when raised
Bolt for holding bracket to
Handle for rotating mast
100mm
150mm inside diameter casing
1·21m
Sand
Concrete and rocks
Rubble (for drainage)
1·40m
CD1012

Fig 10.10: Counterweighted fold-over rotatable 12 metre mast, constructional details

angle iron welded to it to make a clevis as shown in **Fig 10.9**. This arrangement, together with a bolt and nut through the rotating section for the mast, forms the thrust bearing which allows the mast be rotated and a fulcrum point for it to be folded over.

The whole mast is rotated manually using a handle fixed to the bottom of it, though it could be rotated using a home made rotator mechanism as used in Fig 10.8.

The detail of this mast can be seen in **Fig 10.10** and a more general views can be seen in **Figs 10.11 and 10.12**. The lower section of the mast is made out of solid 82mm steel rod.

Although these structures can be built single-handed, the following are areas where some assistance would be of help.

- Inserting the lower half of the mast into the base casing. Two ropes are tied to the top of the lower section, using the holes drilled for the pivot bolt. The section can then be placed with the lower end over the base casing and the top supported on a pair of stepladders. The section can be raised using these ropes, at the same time the lower end is guided into the casing with a section of angle iron.
- Placing the clevis at the top of the mast to enable the bolt to be fitted and inserting the mast into the oversize piping used as the tiltable thrust bearing. These tasks can be eased by using a gin pole with a pulley and rope. The gin pole can be constructed from steel angle iron and clamped to the mast with additional angle iron pieces or steel straps.

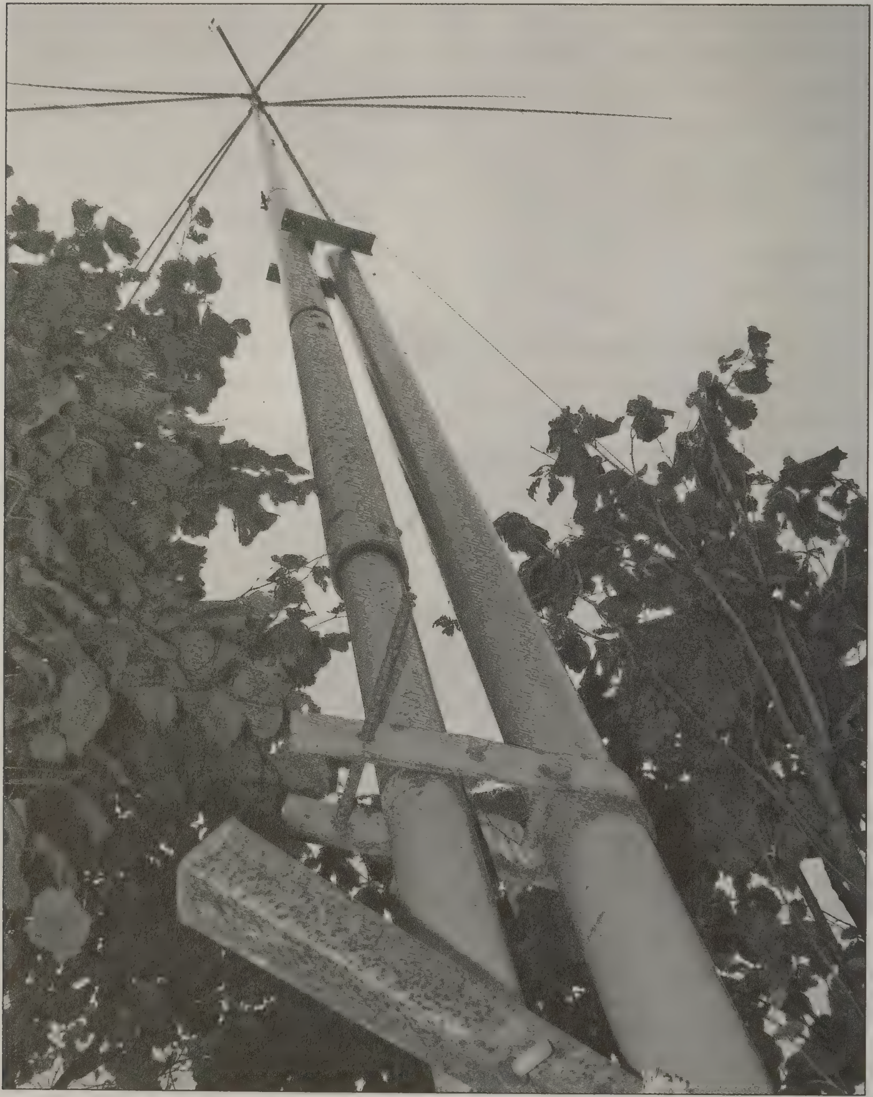


Fig 10.11: Worms eye view of the 12m (40ft) fold-over mast. At the bottom is the angle-iron rotating handle and just above it is the securing bracket.

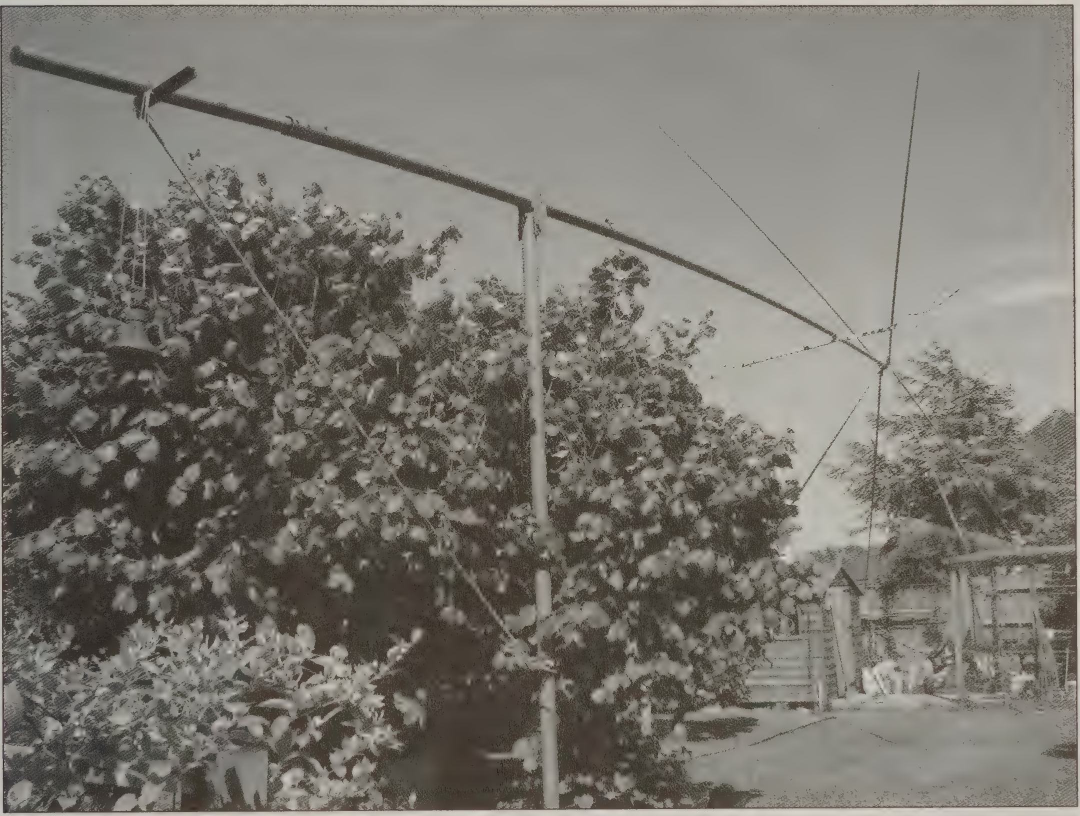


Fig 10.12: 12 metre (40ft) mast and quad folded over. The mast is counterweighted so that it can be raised or lowered without a winch.

Material for steel masts

Steel tubing is usually available in scrap metal yards. Tubing used for antenna masts should be free from damage and excessive corrosion.

The lower sections of a 12metre (40ft) high steel self-supporting mast should be at least 9cm 90mm (3½in) diameter, with a wall thickness 5mm.

Steel tubing is often available, threaded, with screw couplers. These couplers are fine for the purpose for which the tubing was designed ie piping liquid or gas. When tubing is used for antenna supports it is often under some bending stress. Couplers only have a short length of screw thread and will be a source of weakness when tubing is employed as an antenna mast, so do NOT be tempted into making a mast using these couplers.

Steel tubes should only be joined by employing lengths that telescope into each other, with at least 30cm (12inches) of overlap and secured with a nut and bolt. Do not weld the sections together, a 12metre section of steel tubing is very heavy and difficult to manage. It is much easier to assemble a mast in sections.

Ensure the tubing lengths will fit into each other. I once bought a length of tube for a section of an antenna mast. The smaller diameter tubing would not fit into this new section because the inside wall was partially furred with a hard calcite deposit caused by its previous use.

When a small diameter pole is joined to larger diameter pipe, eg scaffolding pole into 8cm (3in) pipe, metal strip or angle iron shims can be used to pack any space between the differing diameters before securing with a nut and bolt.

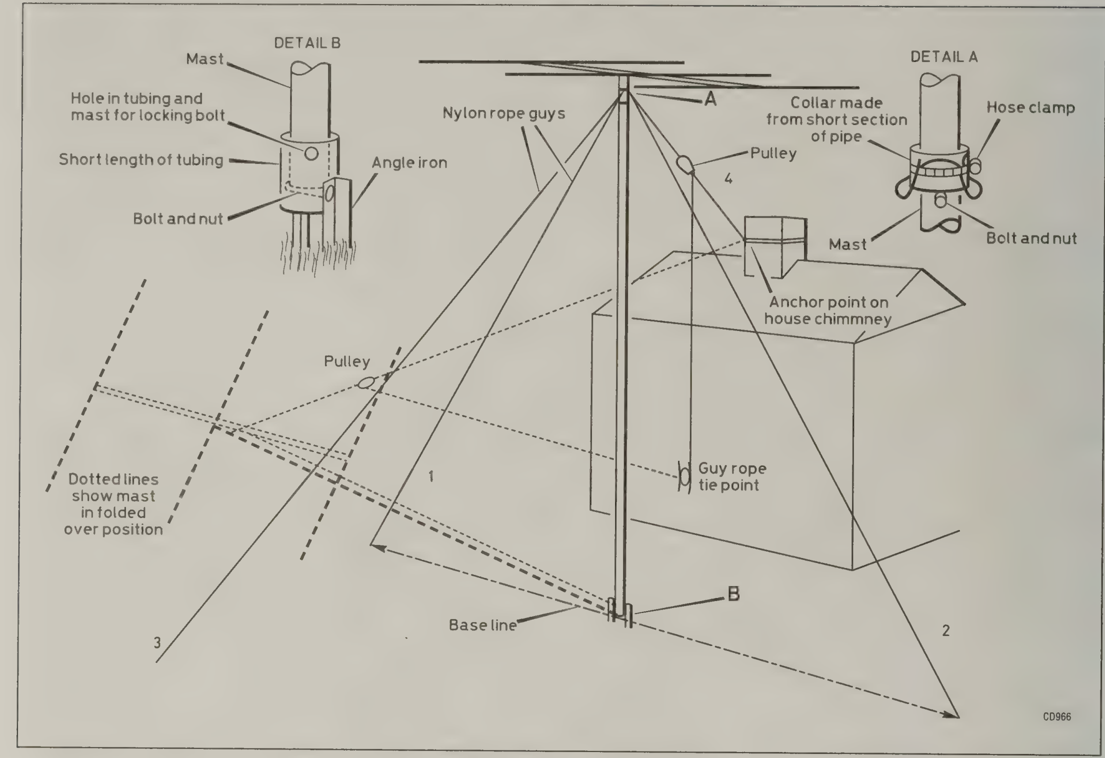


Fig 10.13: Constructional details of the G2XK type of lightweight fold-over mast,

The G2XK lightweight mast

If the heavy engineering required in the foldover masts described above is not to your taste then you might like to consider a lighter weight construction. In the early 1960s, Eric Knowles, G2XK, used the method described below to support a 6-element 28MHz beam on an 11 metre (36ft) boom at a height of 12 metres (40 ft), using only 80mm (3in) diameter thin-wall duralium tubing mast. This large structure weathered many a gale that swept across the Vale of York. Having said that, this is a lightweight mast and should not be used for supporting heavy HF beams.

There is nothing new in this method of supporting, or raising and lowering masts using guy ropes. The military have used the method for many years for supporting fixed wire antennas.

The description that follows is of a similar mast; suitable for supporting a medium sized experimental beam antenna. No special tools or welding equipment are required to construct this structure and is an excellent support for experimental antennas provided the space for the guys is available. Do not use steel tubing for the mast of this design because it is too heavy. Aluminium scaffolding pole is not really suitable for this design of mast because (being thick walled) it is rather heavy, although it could be used for short masts of up to 8metres (25ft) high.

The layout is illustrated in **Fig10.13**. The structure can be used with a fixed mast and rotator, or the mast can be designed so that it can be rotated. In this case provision has to be made to allow the mast to rotate and be folded over. A minimum of four guy ropes are used.

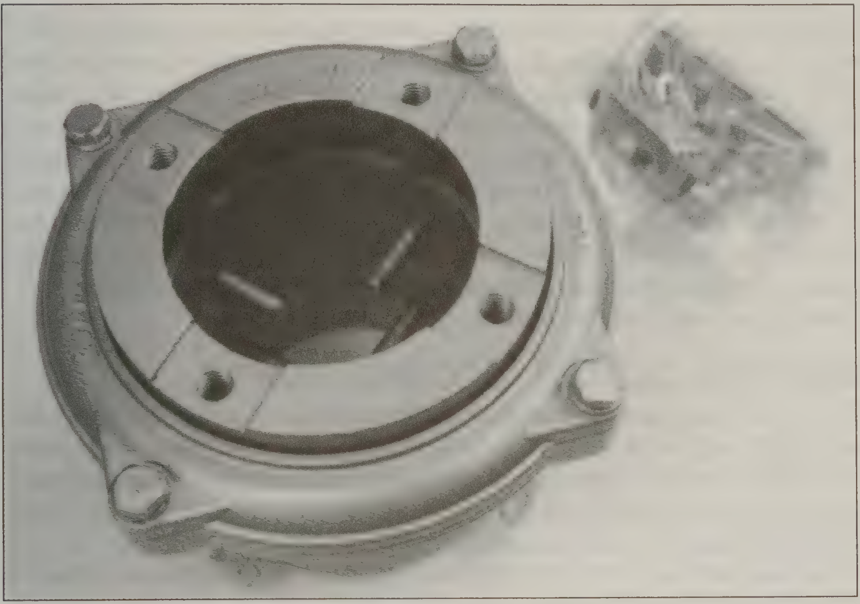


Fig 10.14: The Yaesu GS-065 thrust bearing, suitable for a rotatable guying point on rotatable masts up to 65mm (2½in) diameter. The bearing is upside down showing the bolt holes for fitting the guys.

The anchor point for guy wire four must be above ground level; the chimney of a nearby house is suitable with a lightweight structure. Guy ropes 1 and 2 are anchored along the baseline so that they retain the same tension when the mast is being erected or folded over. The length of guy rope 3 is adjusted so that it is under tension when the mast is in the vertical position. The original G2XK version used two sets of guy ropes but only one set is illustrated in Fig10.13 for clarity.

This structure gains all its strength from its guys, so it is important that the guy ropes are strong and are connected securely, both at the anchorage and the top of the mast. Polypropylene rope (6mm diameter) is a suitable material for the guys, which should ideally be at 45 degrees to the mast. This angle can be reduced if space is limited but this increases the downward pressure on the mast in high winds and increases the chances of the mast buckling.

Commercial mast bearings are available for the top of the mast. One example is the Yaesu GS-065 thrust bearing shown in **Fig 10.14**. The GS-065 requires an adaptor plate to allow the guys to be fixed to the bearing.

If a commercial rotatable guy rope support bearing is unavailable one can be constructed with short length of steel tube, slightly larger in diameter than the mast. Thick steel wire loops can be fixed to the tube using two or three hose clamps; these clamps should be of good quality. The top of the mast is inserted into this tubing. A bolt and nut, through the appropriate point on the mast, holds the guy support collar in position. Detail A of Fig10.12 illustrates this.

The guy anchorage can be constructed from a one metre (40in) or so length of angle iron, cut to a point one end and a hole drilled in the other. This can be driven into the ground at 90° to the angle of pull. The guy anchorage may need to be more substantial for very large masts and/or if the soil is light and sandy. The guy rope should be connected to the guy anchorage with a D-clamp. A pulley is required for the halyard to enable the mast to be hauled up; a good quality clothesline pulley is suitable.

The base pivot point comprises two lengths of angle iron, cut to a point at one end and a hole drilled at the other. The two angle iron pieces are driven into the ground, with the holes aligned so that the pivot bolt can be fitted. If the design calls for a rotatable mast then a small section of tubing, whose internal diameter is slightly larger than the outside diameter of the mast, is pivoted to the angle iron. The mast fits inside this section of tubing and is free to rotate. Holes can be drilled through the base tubing and the mast to enable the structure to be locked on any particular heading. Detail B of Fig10.12 shows how this is done. Lightweight sections of thin-wall tubing can be joined together using a short joining section as shown in Chapter 9.

ROUTING CABLES INTO THE HOUSE

The business of modifying the house for amateur radio by using it as an antenna support was discussed earlier. A further consideration might be how to route coax cables into the house. You might have a multi-band beam with its coax cable and rotator control cable, plus a VHF antenna and a long wire antenna for the lower frequency bands. And of course there is the earth connection.

The time-honoured way of dealing with this problem is to drill lots of holes in the window frame. However, modern houses (and a lot of older ones) use double-glazing, with its plastic and metal window frames. Using the window frame as a route for cables is not feasible and another method must be sought. Ian White, G3SEK, used a method of routing the cables by inserting a length of plastic drainpipe through the wall [3]. What follows is how he did it.

In a traditional British brick house with cavity outside walls, the job is well within the reach of a competent DIYer and it should make very little mess. Think of it as installing a waste pipe for the kitchen sink, because 40mm sink waste pipe is probably what you'll need - though it's always good to leave enough room for more antennas in the future! You'll also need a good electric hammer drill, at least one masonry bit of about 10mm diameter that is long enough to go right through the double wall, a shorter masonry bit of about the same size, a fairly large hammer and a long, narrow cold chisel.

Plan very carefully to find the best place to drill. Leave at least one whole brick away from doors or window frames. Remember that the frame has a solid lintel across the top, extending outwards on both sides. Check both the inside and the outside of the wall with a live cable and metal detector to be sure that you won't meet any nasty surprises. If yours is a wooden-framed house with a brick outer skin, take great care to avoid structural timbers.

First you need a pilot hole, right through the wall, and then you're going to enlarge the hole from each side by continuing around a circle. Start from the outside and drill through the mortar, halfway along a brick, as shown in **Fig10.15**.

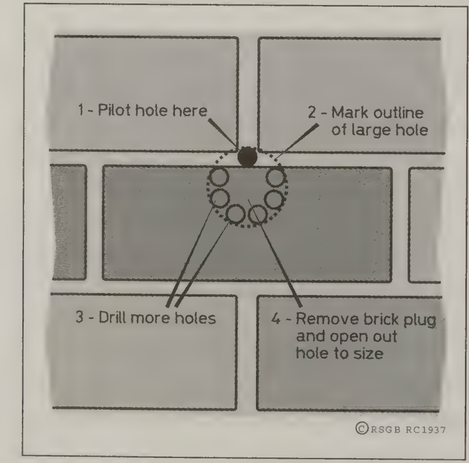

1 - Pilot hole here
2 - Mark outline of large hole
3 - Drill more holes
4 - Remove brick plug and open out hole to size
©RSGB RC1937

Fig 10.15: How to drill a large hole through bricks.

Use one of the shorter masonry bits to start the hole, and take care to drill it accurately at right angles to the wall - the mortar joint will guide you. (It's just possible that you will hit a metal wall tie. If you do, move along to the next brick.) When you break through into the wall cavity, change to the longer bit and carry on drilling. To avoid pushing off a big patch of plaster from the inside wall, stop when you're within a few centimetres of breaking through. Switch off the hammer action of the drill, and continue with very gentle pressure until you're right through both walls.

Now mark out a circle on each side of the wall, rather larger than the diameter of the pipe, as shown in Fig10.15. The pilot hole is at the top of each circle. Work separately from each side, using the shorter masonry bit. Drill a ring of holes as close together as possible, stopping when you're through to the cavity. Because it's important to start each hole in exactly the right place, it helps to begin with a smaller bit, using the drill at slow speed with the hammer action off. When the hole is well started into solid brickwork (or breeze block on the inside wall) it's safe to change to the larger bit with the faster hammer action. Next you need to open out the hole from each side, using the cold chisel and occasionally perhaps the electric drill, until the pipe will slide right through.

Chip away carefully without too much violence so as not to crack the outside brick or do any unnecessary damage to the interior plasterwork - and try to pull the central plugs out rather than pushing them into the cavity. With care you can make almost as good a hole as a professional using a big core drill. Make sure that the pipe will slide through horizontally, or sloping a few degrees upward from the outside so that rainwater won't run in. Set the end of the pipe just proud of the inside wall, and leave any overhang outside. Fill the gaps around the pipe with mortar or exterior filler on the outside and plaster or interior filler on the inside, and let it all set solid. The next day saw off the outside end of the pipe, a few centimetres away from the wall. Now you can start to thread the cables. A 45° or right-angle pipe elbow, facing downwards, fixed to the pipe where it emerges on the outside wall, may be used to help keep the rainwater out. When all the cables are in place, stuff in plastic foam for draught proofing, or use aerosol-expanding foam.

This method of installing a pipe is quite easily reversible before you move house. The pipe will pull out from the outside with a bit of effort, and you can plug and plaster over the hole in the inside wall. On the outside, you'll only need to replace one brick if you have followed the drilling pattern in Fig10.14

WIND LOADING

The saying that "if you haven't had an antenna fall down then you don't build big enough antennas" might sound very smart but it is hardly good engineering practice. Bridge building engineers would hardly get away with it.

Most antennas are brought down by very strong winds so it is important to consider the effect of windloading of your antenna installation. While there are excellent articles on the subject, for example [4], a few suggestions are given here so that you can get some idea of the forces involved.

G3SEK [5] notes that the round figures that stick in his mind are that at 100mph, every square foot of exposed area suffers a sideways pressure of 25 pounds; or that at 45-50m/s the wind force is about 150kgf/m^2 (kilograms force per square metre). So how do you know how many square metres or feet you antenna installation is? To avoid any aerodynamics the best way is to simplify the parts of the elements to a 'flat slab' area. So that a pole 3m long and 50mm (.05m) diameter is a flat slab 0.15m^2.

Assessing the exposed areas

This is where the calculations become simple. Take, for example, the compact HF beam mounted on the roof of the house shown in Fig 10.3. This beam has two elements, which are 4.49m long and 25mm in diameter. The flat slab area of the elements is 4.49 x 0.025 x 2 = 0.2245m^2

The boom is 2.1m long and 0.035m diameter = 2.1 x 0.035 = 0.08m^2

The loading coils and spokes at the ends of the elements are complicated so they have been modelled as four cylindrical objects 0.3m long by 0.06m in diameter. This gives an area of 0.3 x 0.06 x 4 = 0.072m^2

The mast fixed to the chimney is around 1m long and 0.05mm diameter = 0.05m^2. For the rotator 0.15m x 0.13m = 0.02m^2 has been allocated.

This totals 0.225 + 0.072 + 0.05 + 0.02 = 0.367m^2, or for rough calculation 0.4m^2.

The boom has not been included because it would be end on to the wind if the beam were facing into wind. If the beam were to be rotated 90 degrees to the wind then the area facing the wind would be

0.08 + 0.06 + 0.05 + 0.02 = 0.21 or say 0.2m^2.

Calculating the wind pressure

To work out the force acting on the antenna structure by the wind, see **Fig10.16**.

This antenna has a total area of 0.4m. The sideways force on the antenna with a 45m/s (100mph) wind, according to Fig10.16 is 128kgf/m^2 x 0.4 = 51kg. By turning the antenna so that the elements are sideways to the wind, the area facing the wind is reduced to 0.2m^2 and the sideways force is reduced to 10.3kg.

There are leverage forces that need to be taken into consideration with unsupported masts that extend above the supporting structure, such as a wall bracket, chimney bracket or guys on a mast. That is why an antenna should be fixed as close support or rotator as possible. If you have a Christmas tree of antennas turned by one rotator then a rotator cage is a must.

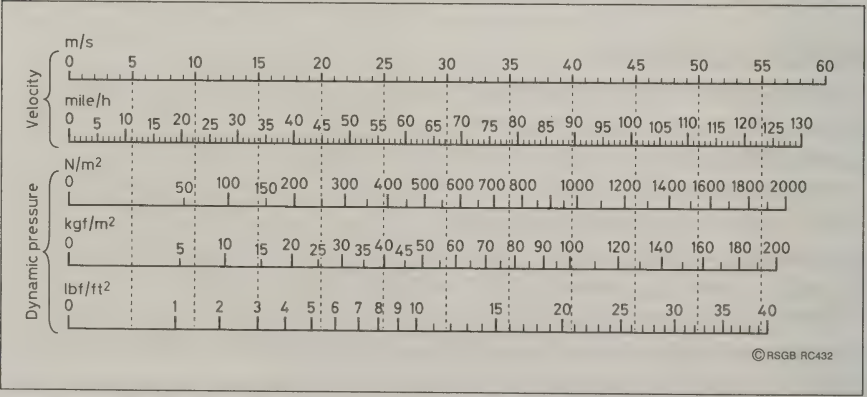


Fig 10.16: Conversion between wind speed and force per unit area.

Of course, these calculations are a simplification of the real world. The wind comes in gusts and there is a lot of turbulence over the roof. Nevertheless, the method of estimating wind forces by G3SEK does give some idea of the forces that will be encountered and will enable you to engineer the structure accordingly.

REFERENCES

[1] 'In Practice', Ian White, G3SEK, *RadCom* March 1995.
[2] 'The Paul Buyan Whip', Alfred W Hubbard, K0OHM, *QST* March 1963,
[3] 'In Practice', Ian White, G3SEK, *RadCom* November 1998.
[4] 'Wind loading' by D J Reynolds, G3ZPF. *RadCom* April and May 1988 (reprinted in *The HF Antenna Collection*, RSGB).
[5] 'In Practice', Ian White, G3SEK, *RadCom*, January 1995.

11

Transmission lines

For an antenna to function efficiently it should be installed as high and clear of buildings, telephone lines and power lines as is practically possible. On the other hand, the transmitter that generates the RF power for driving the antenna is usually located in the shack, some distance from the antenna feedpoint. The connecting link between the two is the RF transmission line or feeder. Its sole purpose is to carry RF power from the transmitter to the antenna, or received signals from the antenna to the receiver, as efficiently as possible.

Any conductor that has appreciable length compared with the wavelength will radiate power if it is carrying RF current; in other words it becomes an antenna. The transmission line must be designed so that RF power being carried to the antenna does not radiate.

Radiation loss from transmission lines can be prevented by using two conductors so arranged and operated that the electromagnetic field from one is balanced everywhere by an equal and opposite field from the other. In such a case the resultant field is zero; in other words, there is no radiation. This is illustrated in **Fig 11.1**.

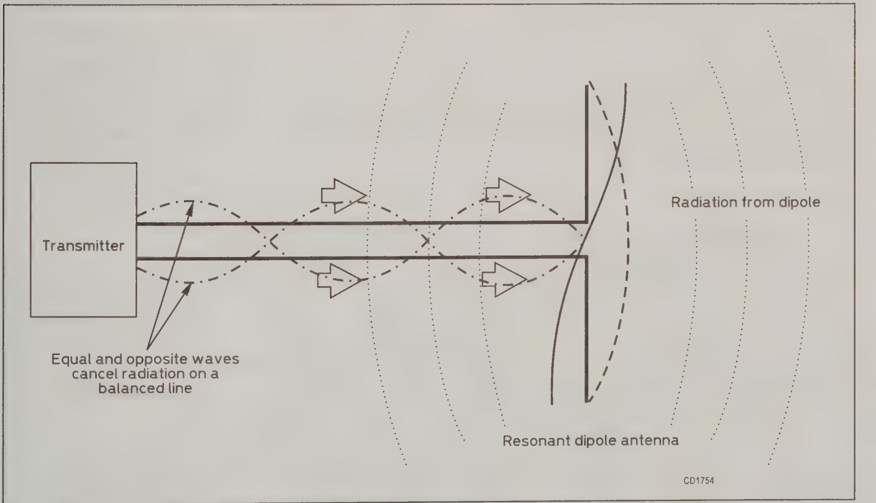


Fig11.1: RF energy on a transmission line connected to an antenna. No radiation occurs on the line provided the RF energy on each of the lines is equal and opposite. Once the energy reaches the antenna there is no opposition to radiation.

TRANSMISSION LINE BASICS

Characteristic impedance

Transmission line with its two conductors in close proximity it can be thought of as a series of small inductors and capacitors distributed along its whole length. Each inductance limits the rate at which each immediately following capacitor can be charged when a pulse of electrical power is fed to one end a transmission line. The effect of the LC chain is to establish a definite relationship between current and the voltage of the pulse. Thus the line has an apparent impedance called its characteristic impedance or surge impedance, whose conventional symbol is Zo. Transmission line characteristic impedance is unaffected by its length.

Velocity factor

With open wire air-spaced lines the velocity of an electromagnetic wave is very close to that of light. In the presence of dielectrics other than air used in the construction of the transmission line (see below) the velocity is reduced because electromagnetic waves travel more slowly in dielectrics than they do in a vacuum. Because of this, the wavelength as measured along the line will depend on the velocity factor that applies in the case of the particular type of line in use. The wavelength in a practical line is always shorter than the wavelength in free space.

Mismatch and SWR

The impedance at the feedpoint of an antenna may not be exactly the same as the characteristic impedance of its associated feeder. The antenna is then said to be mismatched to the feeder.

When a wave travelling along a transmission line from the transmitter to the antenna (incident wave) encounters impedance that is not the same as Zo (discontinuity) then some of the wave energy is reflected (reflected wave) back towards the transmitter.

Whenever two sinusoidal waves of the same frequency propagate in opposite directions along the same transmission line, as occurs in any system exhibiting reflections, a static interference pattern (standing wave) is formed along the line, as illustrated in **Fig 11.2**.

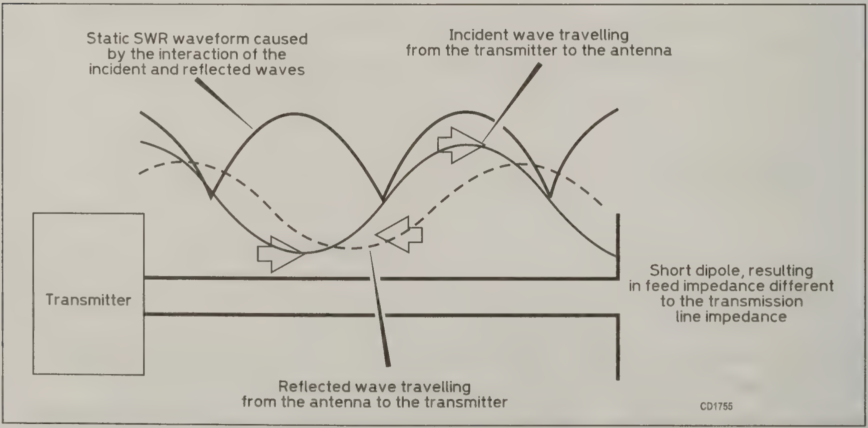

Static SWR waveform caused by the interaction of the incident and reflected waves
Incident wave travelling from the transmitter to the antenna
Transmitter
Short dipole, resulting in feed impedance different to the transmission line impedance
Reflected wave travelling from the antenna to the transmitter
CD1755

Fig 11.2: Creation of a standing wave on a transmission line.

For the purposes of quantifying reflection magnitude, however, we are interested in the amplitude of the voltage or current maxima and minima. Standing Wave Ratio (SWR) is defined as the ratio of the voltage or current maximum to the voltage or current minimum along a transmission line, as follows:

$$\text{SWR} = V_{max} / V_{min} = I_{max} / I_{min}$$

SWR can be measured using either a current or voltage sensor as it is moved along the transmission line and comparing the maximum with the minimum. The maximum must always be greater than the minimum, thus SWR is always greater than, or equal to, one. If no reflections exist, no standing wave pattern exists along the line, and the voltage or current values measured at all points along the transmission line are equal. In this case impedance match is perfect and SWR equals unity.

A more convenient method of measuring SWR is to use a reflectometer. This instrument comprises two power meters, one reading incident power and the other reflected power. Power detector directivity is possible because the incident wave voltage and current are in phase and in the reflected wave, 180° out of phase.

It is often thought that a high SWR causes the transmission line to radiate. This is not true provided the power on each line is equal and opposite as shown in Fig 11.1.

Transmission line as impedance transformer

Impedance can be defined by the ratio of current and voltage. This will be familiar to you when looking at the current and voltage distribution of the standing wave on a dipole antenna as shown in Fig 11.1. The voltage is high and the current zero at the end of the dipole (high impedance) while at the centre of the dipole the voltage is low and the current high (low impedance). The centre is obviously the best place to feed the antenna when using low impedance transmission line.

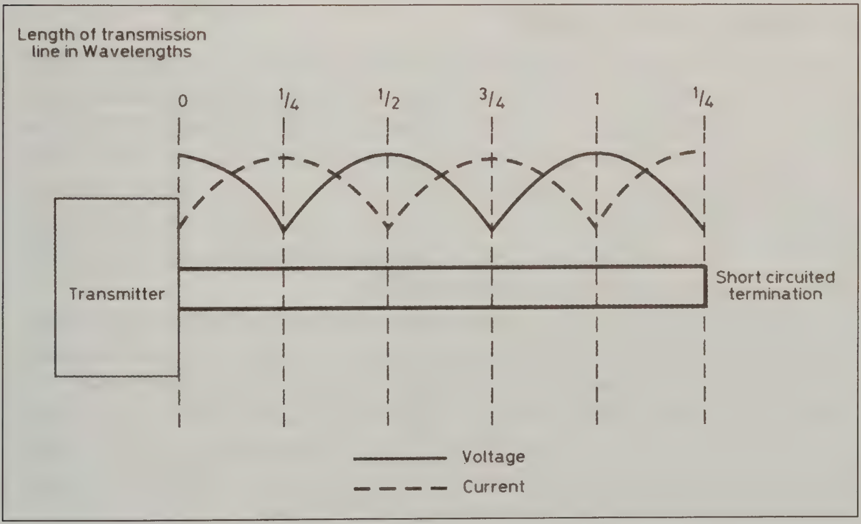

Length of transmission line in Wavelengths
0
1/4
1/2
3/4
1
1/4
Transmitter
Short circuited termination
Voltage
Current

Fig11.3: Transmission line terminated with a short. Note the points where values of the same impedance (and opposite impedance) recur.

If the transmission line is terminated with a short circuit, the impedance at that point will be very low as shown in **Fig 11.3**. It can be seen that the voltage is zero and the current very high at that point. The standing wave pattern shows that this very low impedance is repeated at every half-wave point down the line. On the other hand, the impedance will be very high quarter of a wavelength down the line. This characteristic of transmission lines is often used as an impedance transformer.

Losses in transmission line

Practical transmission line has losses due to the resistance of the conductor and the dielectric between the conductors. As in the case of a two-wire line, power lost in a properly terminated coaxial line is the sum of the effective resistance loss along the length of the cable and the dielectric loss between the two conductors. Of the two losses, the resistance loss is the greater; since it is largely due to the skin effect and the loss (all other conditions remaining the same) will increase directly as the square root of the frequency.

Measurement of coaxial cable loss

It is useful to be measure the loss of coaxial cable, particularly if it has been in use for some time. The classic method of measuring coaxial cable loss is to terminate the cable with a dummy load that is equal to the Zo of the line. Then use a power meter, first at the transmitter end and the load end ensuring that the transmitter power is maintained at a constant level during the test. Then calculate the loss from the difference in power readings using the formula:

$$\text{dB loss} = 10 \log (P_1/P_2)$$

where P_1 is the power at the transmitter end and P_2 is the power at the dummy load.

Many ATUs have a power meter and an internal dummy load, which make them ideal for this test.

Losses due to SWR

The normal losses to be found transmission line are shown in **Fig 11.4**, which shows approximate losses for 450-ohm twinline and RG213 coaxial cable. Additional losses occur due to antenna/transmission line mismatch (SWR), also shown in Fig 11.4. These losses are for a transmission line over 30m (100ft) long. SWR losses on the HF bands are not as great as is often thought, although at VHF and UHF it is a different matter. As you can see from Fig 11.4, even an SWR of 5:1 on a 30m length of RG213 coax at 28MHz, the attenuation is only just over 1dB over the perfectly terminated loss.

A reading of SWR due to a mismatch at the transmitter end of the transmission line will be lower than if the measurement were taken at the load (antenna) end. The reason is that the losses on the line attenuate the reflected wave. This means you can use an SWR meter to measure transmission line loss, using the power meter method (use a load that creates a mismatch, say 100 ohms) described above. Measure the SWR at the transmitter and at then at the antenna. Use the graph in **Fig 11.5** to determine the cable loss.

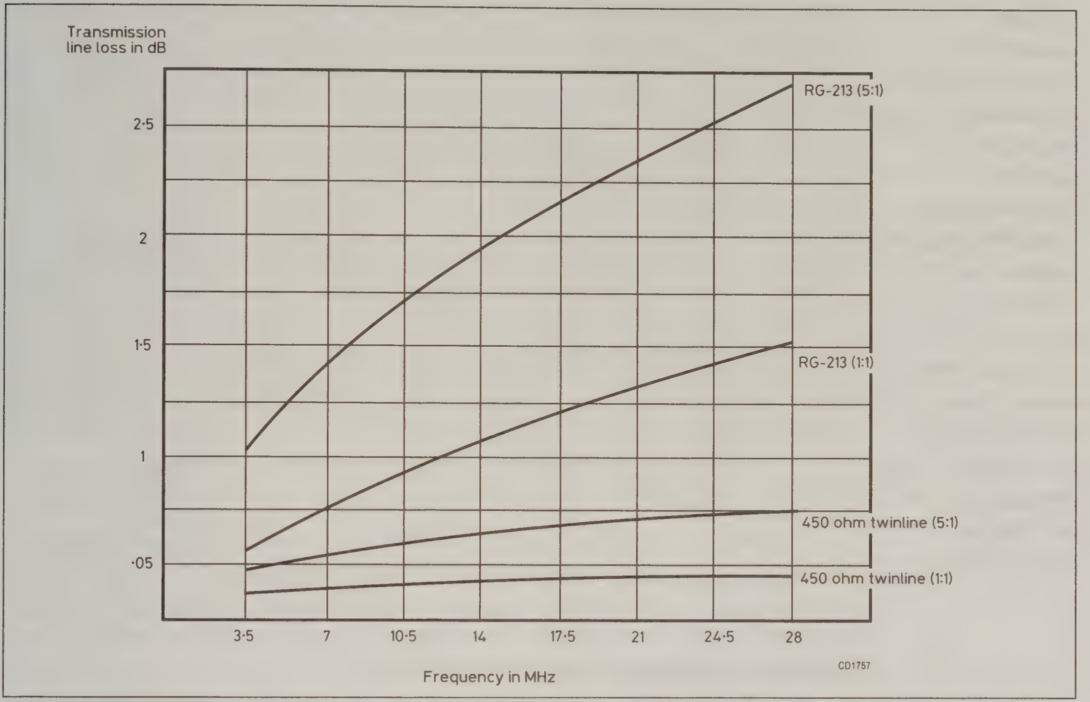


Fig11.4: Graph showing losses on a 30m (100ft) of 450-ohm twin line and RG213 coaxial cable at an SWR of 1:1 and 5:1.

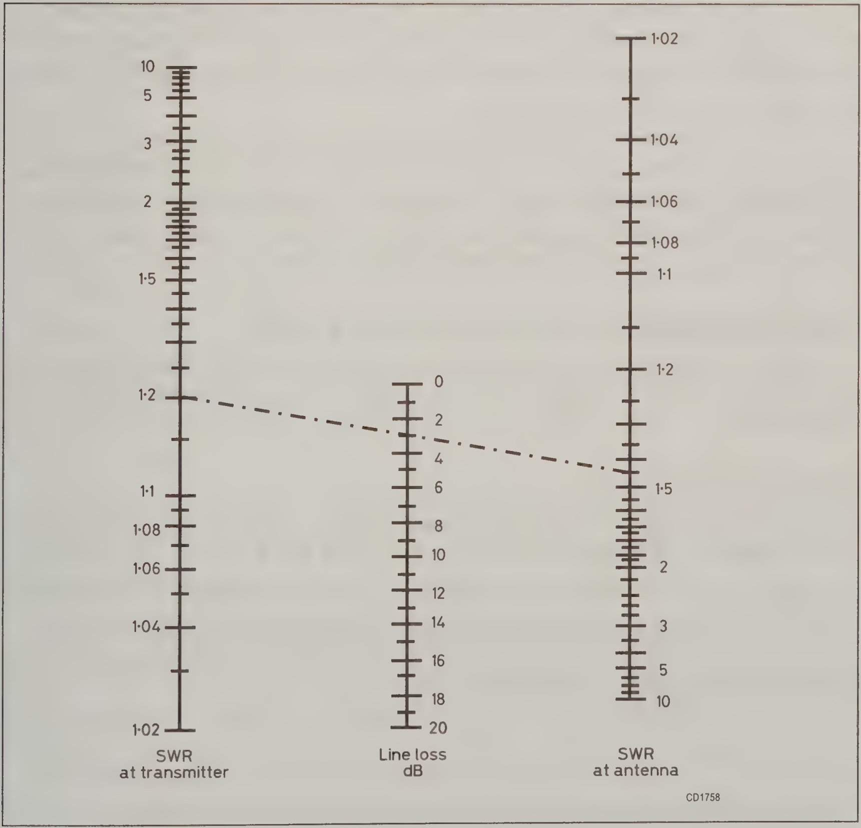


Fig11.5: Nomograph for calculating transmission line loss using an SWR meter.

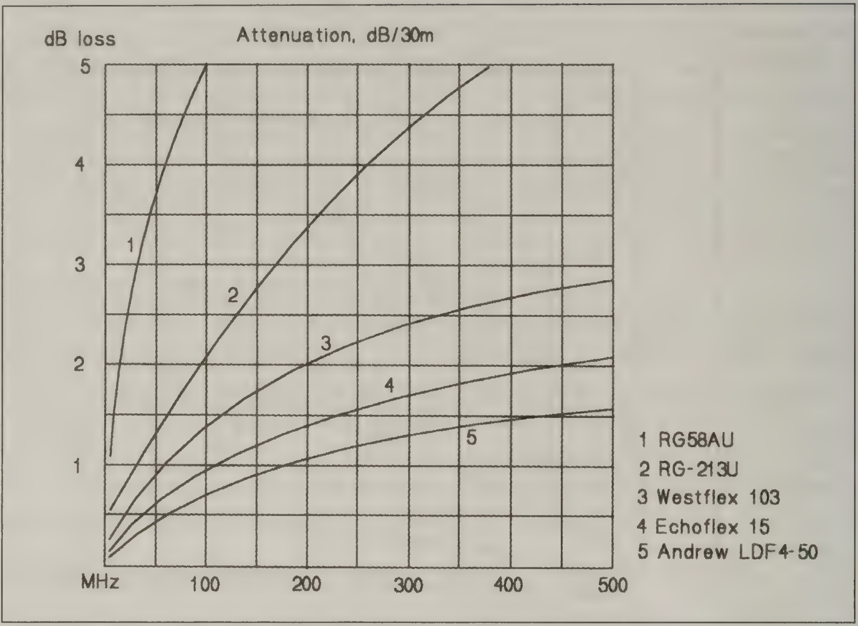


Fig 11.6: Attenuation characteristics of various 30m (100ft) lengths of correctly terminated coax cables. With the exception of RG58 coax the attenuation differences of the various cables below 30MHz are not significant. The differences at VHF and UHF are another matter.

Low-loss coax, is it worth it?

The attenuation factors of various correctly terminated coax cables are shown in **Fig 11.6**. These attenuation figures are for 30m (100ft) lengths and indicate that for frequencies below 30MHz there is not much to be gained by using expensive low-loss coax feeders. The method of construction of these cables to reduce loss is described and illustrated below.

At VHF, and particularly UHF frequencies, it is a different matter. Good quality coax can really enhance a station's performance. On a typical UHF installation at least a 3dB increase should be possible by replacing RG213 with, say, Ecoflex. If this doesn't sound much remember that generally the size a VHF/UHF antenna array has to be doubled to get 3dB gain.

TRANSMISSION LINE STRUCTURE

Two types of transmission line have been used to construct antenna systems described in the antenna chapters in this book. These are twin-line feeder and coaxial cable.

Twin-line feeder

Twin-line feeders can be constructed from two copper wires supported at a fixed distance apart using insulated spacers as shown in **Fig 11.7**. This type of construction is often known as 'open-wire feeder'. Spacers may be made from insulating material, such as plexiglas, polyethylene or plastic. The spacers shown in Fig 11.7 are specifically made for the job. The characteristic impedance of such a line can be calculated with the formula

$$Zo = 276 \log_{10} 2S / d$$

Where S is spacing between the wire centres and d is wires diameter.

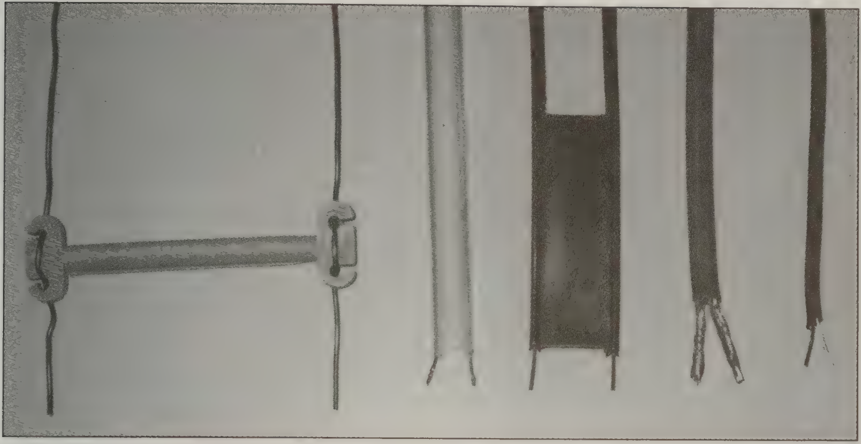


Fig11.7: Open wire line constructed using 1mm diameter copper wire and spacers. 300-ohm twin line with polyethylene insulation, 450-ohm 'window' twin line, 75-ohm heavy duty twin line, 75-ohm light weight twin line.

The construction using 1.5mm diameter copper wire and spacers hold the wire around 75mm apart. Using the formula this gives a Zo of 550 ohms. If 1mm diameter wire had been used, the Zo would have been close to 600 ohms.

The 300-ohm twin line (the light coloured line shown in Fig 11.7) is constructed by moulding the conductors along the edges of a ribbon of polyethylene insulation and for this reason is sometimes known as ribbon line. This type of feeder is convenient to use but moisture and dirt tend to change the characteristic of the line.

A further variation of commercial twin-line feeder is 'window-line', which has windows cut in the polythene insulation at regular intervals. This reduces the weight of the line and breaks up the surface area where dirt and moisture can accumulate.

Coaxial cable

Coaxial cable is the type of transmission line used mostly in amateur radio installations. The two conductors of the transmission line are arranged coaxially, with the inner conductor supported within the tubular outer by means of a semisolid low-loss dielectric.

Coaxial cable has advantages that make it very practical for efficient operation in the HF and VHF bands. It is a shielded line and has a minimum of radiation loss. Since the line has little radiation loss, nearby metallic objects have minimum effect on the line because the outer conductor serves as a shield for the inner conductor.

Electromagnetic waves tend to propagate along the surface of conductors, rather than inside, due to the phenomenon of skin effect. Coaxial cable performance depends upon the conductivity and size of the outer surface of the inside conductor and the inner surface of the outer conductor.

The centre conductor of a coaxial cable may consist of either a single wire of the desired outer diameter, or from a twisted bundle of smaller strands. Stranded centre conductors improve cable flexibility while solid centre conductors provide the greatest uniformity of outer diameter dimension, which contribute to stable electrical characteristics.

The outer conductor of coax cable ideally should ideally be made from a solid conductive pipe but this construction makes the cable difficult to bend.

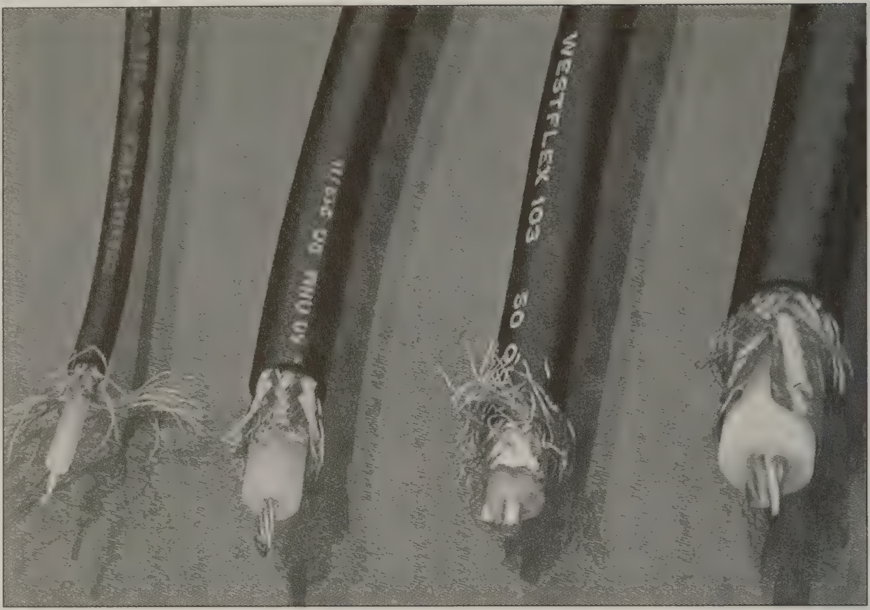


Fig 11.8: Four examples of coaxial cable. (left to right) 50Ω RG58C/U, 50Ω RG213U, Low loss Westflex 103 (50Ω coax same diameter as RG213) and 50Ω very low loss Ecoflex 15 coax . A very useful type of coax is mini-8 which is a compromise between RG58 and RG213 (not shown).

The flexibility and bend radius of such cables can be improved by corrugating the outer conductor; examples are shown in **Fig 11.8**.

Nearly all of the popular flexible coaxial cables employ braided outer conductors. These are not as effective electrically as solid outer conductors because gaps in the woven outer conductor permit some signal leakage or radiation from the cable, increasing the attenuation at higher frequencies. This effect can be minimised by adding a layer of copper foil under the braid.

The dielectric material that separates the outer conductor of a coaxial cable from its centre conductor determines the intensity of the electrostatic field between conductors and maintains the physical position of the inner conductor within the outer conductor.

Common dielectric materials for coaxial cable include polyethylene, polystyrene and Teflon®.

The least lossy dielectric material is a pure vacuum, which is totally impractical for use as a cable dielectric. However, the electromagnetic properties of air or gaseous nitrogen are very similar to a vacuum and can be used by mixing low-cost polyethylene with low-loss nitrogen. This is accomplished by bubbling nitrogen gas through molten polyethylene dielectric material before the polyethylene solidifies. This material is variously known as cellular polyethylene dielectric, foam dielectric, or poly-foam. It has half the dielectric losses of solid polyethylene at a modest increase in cost.

The characteristic impedance of most coax cable used in amateur radio installations is usually 50 ohms. Cable of other impedances is used for impedance transformers and baluns (described later). Other cables are available in an impedance of 75 ohms. The impedance of coaxial cable is often printed on the protective vinyl sheath.

In order to preserve the characteristics of the flexible, coaxial line, special coaxial fittings are available. These, and methods of fixing them, are described later.

FITTING COAXIAL CONNECTORS

Fitting coaxial connectors to cable is something we all have to do at sometime or other. If you have had trouble in the past fitting connectors, you should find the methods described here by Roger Blackwell, G4PMK [1] helpful. Although specific styles of connector and cable are mentioned, the methods are applicable to many others.

Cables and connectors

The main secret of success is using the right cable with the right connector. If you're buying connectors, it is important to be able to recognise good and bad types, and know what cables the good ones are for. Using the wrong connector and cable combination is sure to lead to problems. Any information you can get, such as old catalogues, is likely to prove useful, especially if you can get the cable cutting dimensions and equivalents lists.

Cables commonly used in amateur radio are the American 'RG' (RadioGuide MIL specification) types.

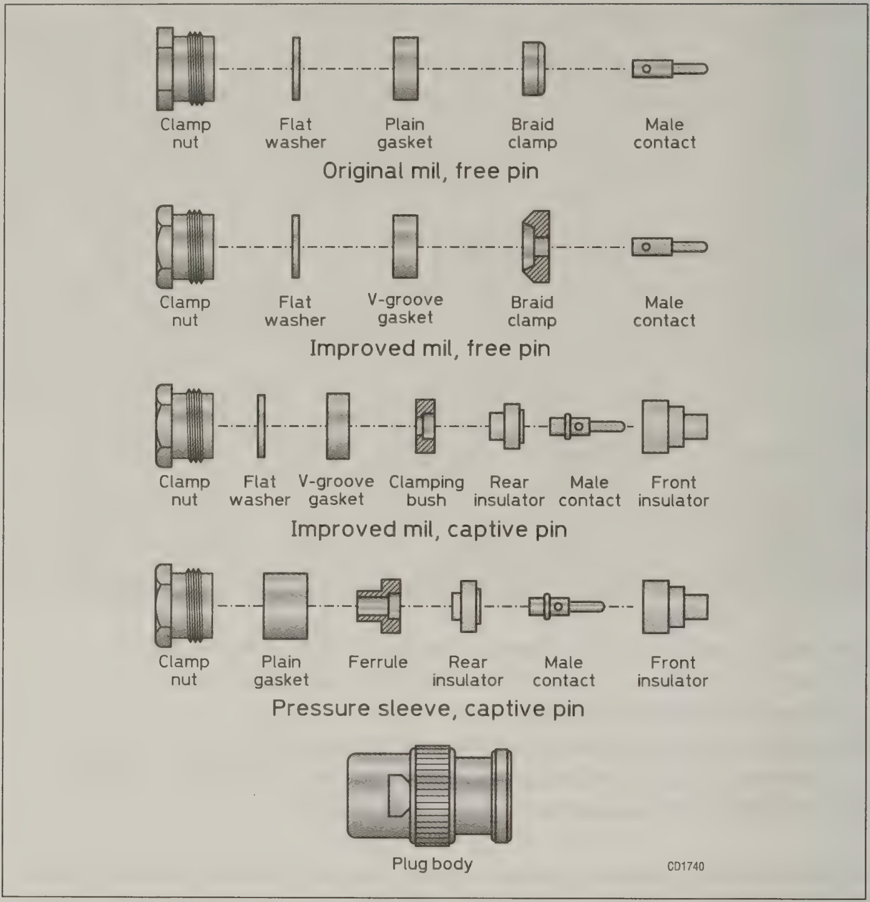
- RG213 is 10.5mm in diameter and is the most common cable used with type N and PL259 connectors.
- RG58 (5mm OD) is one usually used with BNC connectors. If there is any doubt about the quality of the cable, have a look at the braid. It should cover the inner completely.
- There is another useful type of coax cable and that is M-RG8 (often known as Mini-8), which is a compromise between RG213 and RG58. This cable has an outside diameter of 6.5mm.

The three most popular connector types are the UHF, BNC and N ranges. These will be covered in some detail, and a few others mentioned later. If you can, buy connectors from a reputable manufacturer. There are some good surplus bargains about, so a trawl through the boxes at the local rally may prove worthwhile.

The PL259 UHF connector is no good much beyond 200MHz, because the 50 ohms impedance through the plug-socket junction is not maintained. The suitability of N and BNC connectors for use at UHF and beyond is due to their maintaining the system impedance (50 ohms) through the connector. Plugs should have PTFE insulation. The plating should be good quality and there should be two or more solder holes in the body for soldering to the braid. There should be two small tangs on the outer mating edge of the plug, which locate in the serrated ring of the socket and stop the body rotating. If you are going to use small-diameter cable with these plugs, get the correct reducer. It is advisable to buy the reducers at the same time as buying the plugs because some manufacturers use different reducer threads.

With BNC, TNC (like the BNC but threaded) N and C (like N but bayonet) types, life can be more complicated. All these connectors are available in 50 and 75-ohm versions. Be sure you get the right one! All of these connectors have evolved over the years, and consequently you will meet a number of different types. The variations are mostly to do with the cable clamping and centre pin securing method.

Fig 11.9: Types of BNC / N cable clamps.



If you are buying new connectors, then for normal use go for the pressure-sleeve type, which is much easier to fit.

All original clamp types use a free centre pin that is held in place by its solder joint onto the inner conductor. Captive contact types have a two-part centre insulator between which fits the shoulder on the centre pin. Improved MIL clamp types may have either free or captive contacts. Pressure sleeve types have a captive centre pin. As an aid to identification, **Fig 11.9** shows these types. Pressure clamp captive pin types are easy to spot; they have a ferrule or 'top hat' that assists in terminating the braid, a two-piece insulator and a centre pin with a shoulder. Unimproved clamp types have a washer, a plain gasket, a cone-ended braid clamp and a single insulator, often fixing inside the body. Improved types have a washer, a thin ring gasket with a V-groove and usually a conical braid clamp with more of a shoulder. There are variations, so if you can get the catalogue description it helps!

Tools for the job

To tackle this successfully, you really need a few special tools; while they may not be absolutely essential, they certainly help. Most of them you probably have anyway, so it's just a matter of sorting through the toolbox. First and foremost is a good soldering iron. If you never intend to use a PL259, a small instrument type iron is sufficient. If you use PL259s something with a lot more heat output is required. Ideally a thermostatically-controlled iron is best; as with most tools a little extra spent repays itself handsomely in the future.

A sharp knife is another must. A Stanley-type is essential for larger cables, provided that the blade is sharp. For smaller cables, you can use a craft knife or a very sharp penknife. Use sharp blades, cut away from you, and keep the object you're cutting on the bench, not in you hand. Although sharp, the steel blades are brittle and will shatter if you apply excessive force or bend them, with bits of sharp blade shooting all over the place. Dispose of used blades in a box or plastic jar. Model shops have a good range of craft knives, which will also do an excellent job.

A small pair of sharp scissors is needed for cutting braids, and a blunt darning needle (mounted in a handle made from a piece of wood dowelling) is useful for unweaving the braid. A scriber is also useful for this job. You will find a small vice a great help as well. For BNC, TNC and N type connectors, some spanners are essential to tighten the gland nuts. The BNC/TNC spanners should be thin 7/16in AF. Those for type N need to be 11/16 x 5/8 AF. A junior hacksaw is needed to cut larger cables. Finally, if you intend to put heatshrink sleeves over the ends of plugs for outdoor use, some form of heat gun helps, although the shaft of a soldering iron may work. A hot-air paint stripper can be used for this purpose - with care.

Preparing cables

Fitting a plug requires you to remove various bits of outer sheath, braid and inner dielectric. The important knack to acquire is that of removing one at a time, without damaging what lies underneath. To remove the outer sheath, use a sharp knife or scalpel. Place the knife across the cable and rotate the cable while applying gentle pressure. The object of doing this is to score right round the cable sheath.

Now score a line from the ring you just made up to the cable end. If you have cut it just enough, it should be possible to peel away the outer sheath leaving braid intact underneath. If this is not something you've tried before, practice on a piece of cable first. For some connectors, it is important that this edge of the sheath is a smooth edge at right angles to the cable, so it really is worth getting right.

Braid removal usually just requires a bit of combing out and a pair of scissors. Removal of the inner dielectric is most difficult with large-diameter cables. Again, it is important that the end is a clean, smooth cut at right angles to the cable. This is best achieved by removing the bulk of the dielectric first, if necessary in several stages.

Finally the dielectric is trimmed to length. There is a limit to how much dielectric you can remove at one go; 1-2cm is about as much as can be attempted with the larger sizes without damaging the lay of the inner. For the larger cables, it is worthwhile to pare down the bulk of the unwanted material before trying to pull the remainder off the inner. If you can, fit one plug on short cables before you cut the cable to length (or off the reel if you are so lucky). This will help to prevent the inner sliding about when you are stripping the inner dielectric.

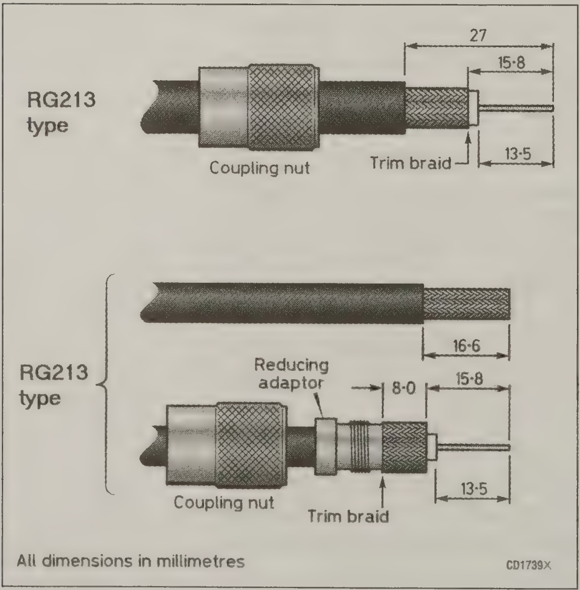
Fitting PL259 plugs

Without reducer, RG213 type cable:
First, make a clean end. For this large cable, the only satisfactory way is to use a junior hacksaw. Chopping with cutters or a knife just spoils the whole thing. Having got a clean end, refer to **Fig 11.10** for the stripping dimensions. First, remove the sheath braid and dielectric, revealing the length of inner conductor required. Do this by cutting right through the sheath and braid, scoring the dielectric, then removing the dielectric afterwards. Next carefully remove the sheath back to the dimension indicated, without disturbing the braid. Examine the braid; it should be shiny and smooth. If you have disturbed it, or it looks tarnished, start again a little further down. With a hot iron, tin the braid carefully. The idea is to do it with as little solder as possible; a trace of a non-corrosive flux such as Fluxite helps. Lightly tin the inner conductor also at this stage.

Now slide the coupling piece onto the cable (threaded end towards the free end). Examine the plug body. If it isn't silver-plated, and you think it might not solder easily, apply a file around and through the solder holes. Now screw the body onto the cable, hard. When you've finished, the sheath should have gone into the threaded end of the connector, the inner should be poking out through the hollow pin, and the end of the exposed dielectric should be hard up against the inside shoulder off the plug. Look at the braid through the solder holes. It should not have broken up into a mass of strands; that's why it was tinned. If it has, then it is best to start again.

If all is well, lightly clamp the cable in the vice, and then apply the iron to the solder holes. Heat it up and then apply solder. It should flow into the holes; if it stays there as a sullen blob, the body isn't hot enough. Now leave it undisturbed to cool before soldering the inner by heating the pin and feeding solder down the inner. Finally, when its all cool, cut any excess protruding inner conductor and file flush with the pin, then screw down the coupling ring. Merely as a confidence check, of course, test for continuity on both inner and outer from one end of the cable to the other, and check that the inner isn't shortened to the braid.

Fig 11.10: PL259 plug assembly.



With reducer, RG58 & Mini 8 type cable:
First, slide the outer coupler and the reducer on to the cable. Next, referring to Fig 11.10, remove the outer sheath without nicking the braid. Now, using a blunt needle, gently unweave the braid a bit at a time until it is all straight and sticking out like a ruff around the cable. Remove the inner dielectric, without nicking the inner conductor; so as to leave the specified amount of dielectric. Tin the inner conductor. Bring up the reducer until the end of the reducer is flush with the end of the outer sheath. Fold the braid back so it lies evenly over the shank of the reducer, then cut

off the excess braid with scissors so that it is not in danger of getting trapped in the threads.

Smooth it down once more, then offer up the plug body and, while holding the reducer and cable still, screw on the plug body until it is fully home. The only really good way of doing this is with two pairs of pliers. Now hold the assembly in the vice and ready the soldering iron.

There has been a spirited discussion from time to time about the advisability of soldering the braid through the holes. Professional engineers use soldered connections or compression types.

Fitting BNC and type N plugs

These are 'constant impedance' connectors; that is, when correctly made up, the system impedance of 50 ohms is maintained right through the connector. It is vital that the cable fits the connector correctly, therefore check that each part fits the cable properly after you prepare it. Refer to **Fig 11.11** for BNC dimensions, and **Fig 11.12** for N types.

Original or unmodified clamp types:

Slide the nut, washer and gasket onto the cable in that order. With the sharp knife, score through the outer sheath by holding the knife and rotating the cable, without nicking the braid. Run the knife along the cable from the score to the end, and then peel off the outer sheath.

Using a blunt needle, for example, start to unweave the braid enough to enable the correct length of dielectric to be removed. Now slip the braid clamp on, pushing it firmly down to the end of the outer sheath. Finish unweaving the braid, comb it smooth then trim it with scissors so that it just comes back to the end of the conical section of the clamp. Be sure that the braid wires aren't twisted.

Now fit the inner pin and make sure that the open end of the pin will fit up against the dielectric. Take the pin off and lightly tin the exposed inner conductor. Re-fit the pin and solder it in place by placing the soldering iron bit (tinned but with the solder wiped off) on the side of the pin opposite the solder hole. Feed a small quantity of solder (22SWG or so works

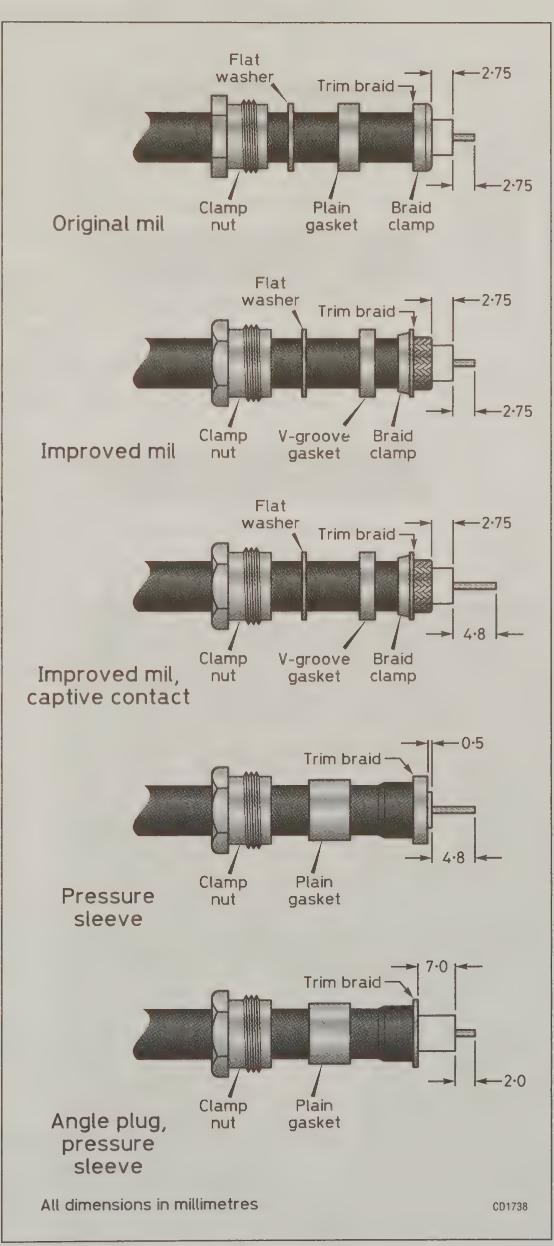


Fig 11.11: BNC dimensions, plugs and line sockets.

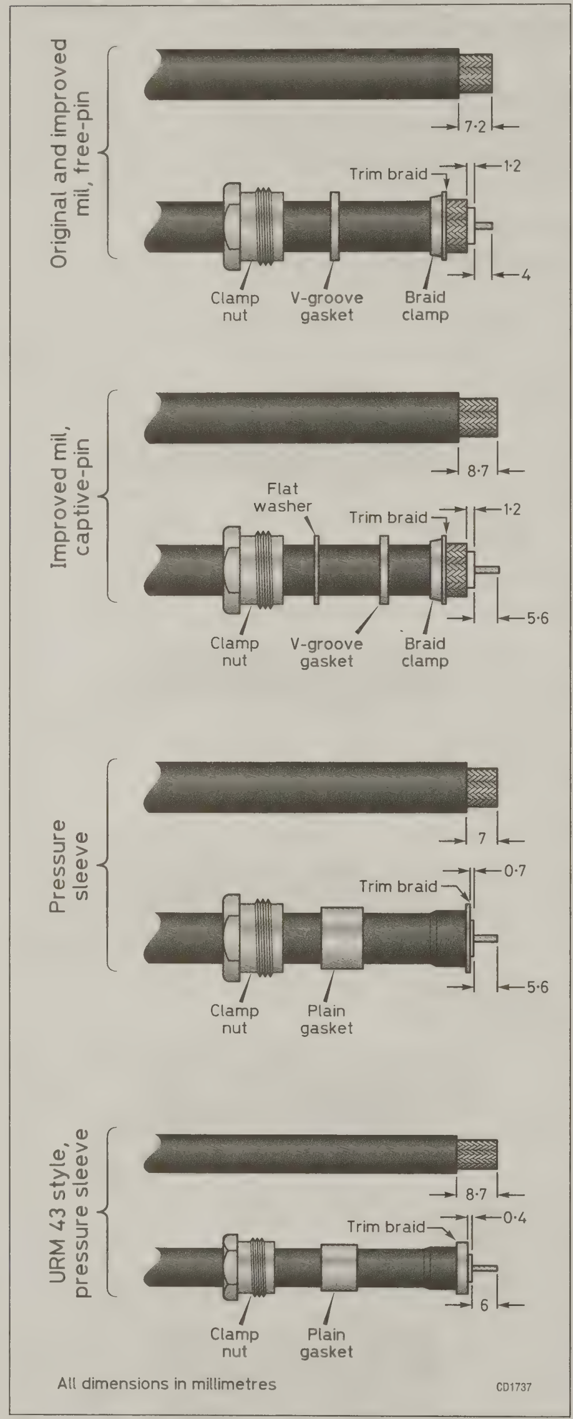


Fig 11.12: N-type dimensions, plugs, angle plugs and line sockets.

best) into the hole. Allow the connector to cool and then examine it. If you've been careful enough, the dielectric should not have melted. Usually it does, and swells up, so with the sharp knife trim it back to size. This is essential, as otherwise the plug will not assemble properly. Remove any excess solder from around the pin with a fine file.

Now push the gasket and washer up against the clamp nut, check the braid dressing on the clamp, and then push the assembly into the plug body. Gently firm home the gasket with a small screwdriver or rod and then start the clamp nut by hand. Tighten the clamp nut by a spanner, using a second spanner to hold the plug body still; it must not rotate. Finally, check the completed job with the shack ohmmeter.

Modified or improved clamp types:

In general, this is similar to the technique for unmodified clamp types described above. There are some important differences, however. The gasket has a V-shaped groove in it, which must face the cable clamp. The clamp has a corresponding V-shaped profile on one side; the other side may be conical or straight sided, depending on the manufacturer. If the clamp end has straight sides, then the braid is fanned out and cut to the edge of the clamp only, not pushed down the sides. Some types have a small PTFE insulator, which is fitted before the pin is put on (common on plugs for the small RG174 cable).

You now appreciate why having the assembly instructions for your particular flavour of plug is a good idea! Still, by using these instructions as a guide, it shouldn't be too difficult to get it right, even if it does not fit the first time.

One important point - if the plug has been assembled correctly and tightened up properly, the clamp will have (intentionally) cut the gasket, which is then rather difficult to re-use. This thin gasket will not stand a second attempt. The thicker gasket types will often allow careful re-use.

Captive contact types:

These have a small shoulder on the pin, and a rear insulator, which fits between the pin and the cable. Most types use a thick gasket and a ferrule, although some use a V-grooved braid clamp and thin gasket. The ferrule type is described first because these are the most commonly available, and the easiest to fit.

First, slip the nut and gasket on to the cable then strip off the correct amount of outer sheath by rotating the cable, producing a neat scored circle. Score back to the end of the cable and peel off the unwanted sheath. Comb out the braid, and with it fanned out evenly around the cable, slide the ferrule (small end first) on to the dielectric-covered inner conductor. Push it home so that the narrow portion of the ferrule slides under the outer sheath, and the end of the outer sheath rests against the ferrule shoulder. Trim the braid with scissors to the edge of the ferrule. Slide up the gasket so that it rests gently against the ferrule shoulder, which will prevent the braid from being disturbed. Using the sharp knife, trim the dielectric back to the indicated dimension, without nicking the inner conductor. Fit the rear insulator, which will have a recess on one side to accommodate the protruding dielectric. Incidentally, if you don't have the size for your particular plug, trim the dielectric until it fits; but don't overdo it!

Now trim the exposed inner conductor to length and check by fitting the pin, whose shoulder should rest on the rear insulator unless the inner has been cut too long. Tin the inner lightly, then fit the pin and solder it by applying the iron tip (cleaned of excess solder) to the side of the pin opposite from the solder hole and feed a small amount of solder into the hole.

Allow to cool, and then remove the excess solder with a fine file. Now fit the front insulator (usually separate from the body) and push the whole assembly into the body. Push down the gasket gently into the plug body with a small rod or screwdriver. Start the nut by hand, and then tighten fully with one spanner, using the other to prevent the body from rotating. Check with the ohmmeter, then start on the other end - remember to put the nut and gasket on first!

Variations:

Angle plugs generally follow a similar pattern to the straight types, except that connection to the inner is via a slotted pin, accessed via a removable cap screw. Tighten the connector nut before soldering the inner. Line sockets are fitted in the same way as plugs.

Interestingly, many connectors used on high-grade low loss cables appear to be solderless. This applies to the N-type male and female connectors used with Ecoflex15 (a high grade coax used at VHF/UHF), see **Fig 11.13**. This connector proved to be very easy to fit.

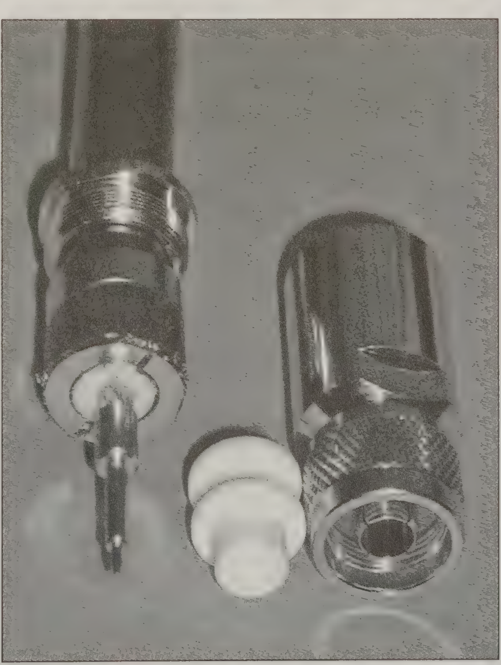


Fig 11.13: Partially assembled N-connector used with Ecoflex 15 coax. Note that the centre pin is a tight push fit over the coax centre conductor. This connector proved to be very easy to fit.

SPLICING COAXIAL CABLE

The radio engineer's method of joining two lengths of coax together is to use coaxial connectors. However, in the description of coax cable splicing by G3SEK [2] that follows, you will see that a splice can be made entirely without connectors. A splice in coaxial cable needs to be as close as possible to an uninterrupted run of cable. In practice this requires four things:

- Constant impedance through the splice.
- As short an electrical length as possible, if it is not possible to make the impedance quite constant.
- Continuous shield coverage.
- Good mechanical properties: strong and waterproof.

At low frequencies, coax can be spliced with a two-pole connector block as shown in **Fig 11.14 (a)**. Tape over the joint and it's done. Even though this creates a non-constant impedance, the electrical length of the splice is so short that it's most unlikely to have any significant effect. The main drawback is that the break in the shield cover provides an opportunity for RF currents to flow out from the inside of the shield and onto the outer surface (the skin effect makes RF currents flow only on surfaces). This may undo all your good efforts to keep RF currents off the feedline, using baluns or feedline chokes.

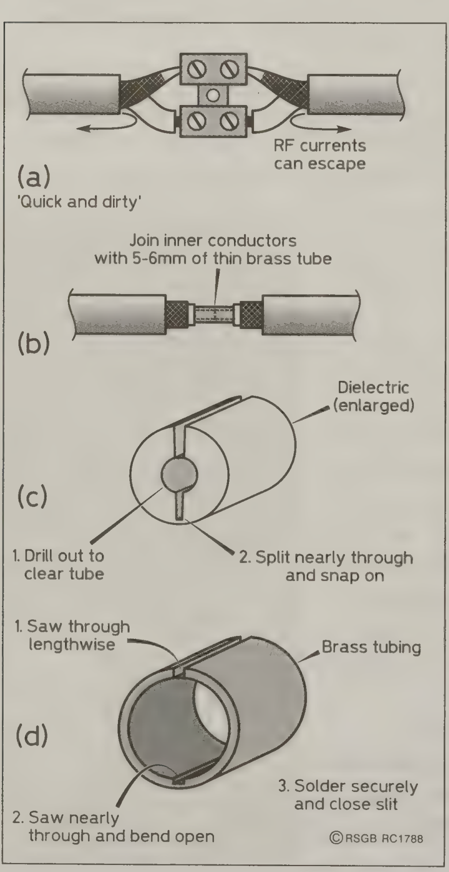

RF currents can escape
(a)
'Quick and dirty'
Join inner conductors with 5-6mm of thin brass tube
(b)
Dielectric (enlarged)
(c)
1. Drill out to clear tube
2. Split nearly through and snap on
1. Saw through lengthwise
Brass tubing
(d)
2. Saw nearly through and bend open
3. Solder securely and close slit
©RSGB RC1788

Fig 11.14: Methods of splicing coaxial cable.

For a truly coaxial splice you need to join and insulate the inner conductor, and then replace the outer shield. Avoid making a big blob of twisted inner conductors and solder if you can, because that will create an impedance bump - a short section of line with a different impedance from the coax itself.

The neatest and electrically the best way to join the inner conductors is to use a 5-6mm (¼in) sleeve of thin brass tubing, see **Fig 11.14(b)**. This is available from good hobby shops in sizes from 1,6mm (1/16in) outside diameter up to 12.7mm (1/2in), in steps of 0.8mm (1/32in); these sizes telescope together, by the way. To replace the dielectric, take a piece of the original insulation, drill out the centre to fit over the sleeve, and split it lengthways so that it snaps over the top, see **Fig 11.14(c)**. To complete the shield on braided coax, one good way is to push the braid away from each end while you join the inner conductor, and then pull it back over the splice. Solder the braid quickly and carefully to avoid melting the dielectric underneath. For mechanical strength you can tape a rigid 'splint' alongside the joint as you waterproof it.

Alternatively the splice can be made using a very short length of air-insulated line of the same characteristic impedance. The inner conductor is joined using tubing as already described in Fig 11.19(b). The outer is made from a short length of brass or copper tubing.

The outer tube is 'hinged' to fit over the joint as shown in **Fig 11.14(c)**. **Fig 11.14(d)** shows how to then solder the whole thing up solidly. This method makes a very strong splice with excellent RF properties.

For 50-ohm air-spaced coax, the ratio of the inner to outer conductor diameters is 0.43, so all you need to do is to choose the right diameters of tubing for the inner and outer conductors. Remember that the relevant dimensions are the outside diameter of the inner conductor, and the inside diameter of the outer conductor. It so happens that air-spaced line needs a larger inner diameter than solid-dielectric, semi-air spaced or foamed line, which conveniently accommodates the wall thickness of the inner sleeve. For RG213 and RG214, the best available choices are 8mm (5/16in) and 4mm (5/32in) outside diameters.

These coaxial splices will be at least as good as a splice using coaxial connectors.

A QUESTION OF BALANCE

Real-life antennas are nothing like the textbook pictures [3]. The textbooks show us a simple dipole; fed in the centre, with electric field lines neatly connecting the opposite halves, and lines of magnetic flux looping around the wires. **Fig 11.15(a)** is a typical version of this pretty picture, showing only the electric field lines for clarity. Everything is symmetrical, and the system is said to be 'balanced' with respect to ground.

The reality of a typical installation is very different. **As Fig 11.15(b)** shows, the electric field lines connect not only with the opposite half of the dipole, but

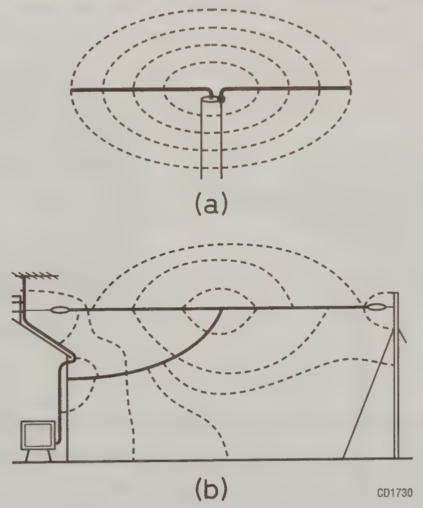


Fig 11.15: (a) Idealised picture of electric fields around a coaxial dipole. (b) The typical reality.

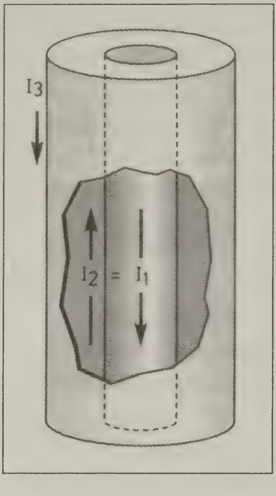


Fig 11.16: Currents on the inside of a coaxial cable (I_1 and I_2) are always equal and in antiphase. The skin effect allows a separate current I_3 to flow on the outside.

also with the feedline, the ground, and any other objects nearby. The magnetic field may be less disturbed, but the overall picture is in no way symmetrical! Although the electromagnetic coupling between the opposite halves of a horizontal dipole makes the antenna 'want' to be balanced, the coupling has to compete with the distorting effects of the asymmetrical surroundings. As a result, practical antennas can be very susceptible to the way they are installed, and are hardly ever well balanced.

Contrast the messy environment of the antenna with the tidy situation inside a coaxial cable shown in **Fig 11.16**. The currents on the centre core (I_1) and the inside of the shield (I_2) are equal and opposite, ie 180° out of phase. The two conductors are closely coupled along their entire length, so the equal and antiphase current relationship is strongly enforced. Also, what goes on inside the cable is totally independent of the situation outside. Thanks to the skin effect, which causes HF currents to flow only close to the surfaces of conductors, the inner and outer surfaces of the coaxial shield behave as two entirely independent conductors. You can hang the cable in the air, tape it to a tower or even bury it, yet the voltages and currents inside the cable remain exactly the same. About the only things you can do wrong with coax cable are to let water inside, or bend it so sharply that it kinks. That's why coax is popular - it is so easy to use.

The problems arise when you connect a coaxial cable to an antenna. If the antenna is in any way unbalanced - which it will be in any practical situation - a difference will appear between the currents flowing in the antenna at either side of the feedpoint.

This difference current is shown in **Fig 11.17** as I_3, and is equal to (I_1-I_2). The current I_3 has to flow somewhere. It cannot flow down the inside of the cable because I_1 and I_2 must be equal, so instead it flows down the outside of the outer sheath. As a result, the feedline becomes part of the radiating antenna. This causes distortion of the radiation pattern, RF currents on metal masts and Yagi booms, and problems with 'RF in the shack'. Even worse can be RF currents flowing in the mains and on TV cables, leading to all manner of EMC problems.

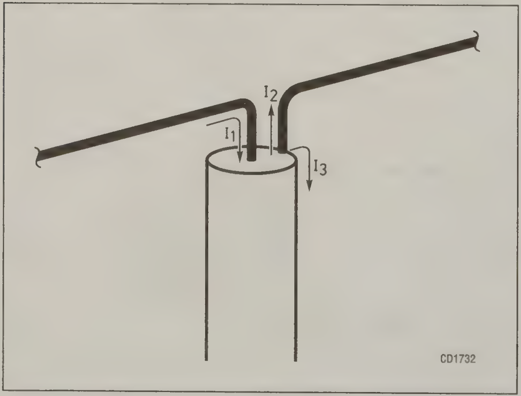


Fig 11.17: If the antenna currents on either side of the feedpoint are unequal, the difference $I_3 = I_1 - I_2$ will flow down the outside of the cable.

BALUNS

The word balun is short for 'balanced to unbalanced'. A balun is a device, which somehow connects a balanced load to an unbalanced coaxial line. It aims to prevent I_3 from flowing, by placing a large series impedance on the outside of the feedline. As a result, the antenna currents can only flow on the inside of the feedline, and the properties of the coaxial cable force the antenna currents at either side of the feed point to be equal and in antiphase, ie balanced. Choke off the difference current, and the antenna currents must adjust themselves to become more symmetrical. By using an appropriate type of balun at the antenna feedpoint, you can effectively prevent stray surface currents on the feedline. As a result, the current distribution on the antenna will adjust itself to become more symmetrical, so the antenna will work better and many of your EMC problems may also disappear.

Choke or current baluns

The simplest baluns are the ones that prevent surface currents from flowing, by forming the coaxial cable into an RF choke at the antenna feed point. (The currents flowing inside the cable are quite unaware that the cable has been coiled up.) At its very simplest, a choke balun can be just a few turns of cable in a loop of diameter 300 to 600mm (6in to12in), see **Fig 11.18(a)**, and in some circumstances this may be all you need. See **Table 11.1** for the number of turns required. Alternatives are to wind the cable around a toroid or a ferrite rod, see **Fig 11.18(b) and (c)**. Yet another alternative popularised by W2DU is to feed the cable through ferrite tubes or beads to form a sleeve as shown in **Fig 11.18(d)**; this is generally lighter and more compact than a coiled choke, but

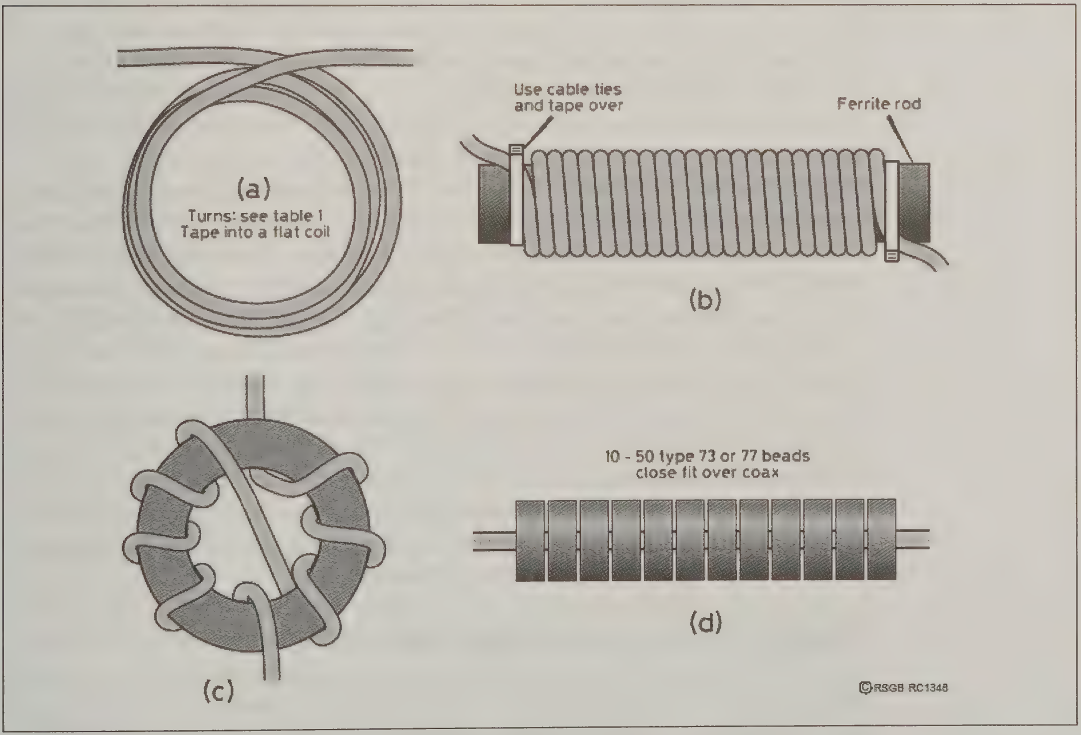


Fig 11.18: Four varieties of choke-type balun. (a) Coil of coaxial cable (typically 6-10 turns - only three turns shown). (b) Coaxial cable on toroid. (c) Coaxial cable on ferrite rod. (d) Ferrite sleeve. These chokes are designed to present a high impedance to unwanted currents on the outside of the coax cable.

Table 11.1: Coiled-coax Feeding Chokes for HF. Wind the indicated length of coaxial cable into a flat coil and tape it together. [Source - W7EL, *ARRL Antenna Handbook*]

	RG213		*RG58*	
MHz	**feet**	**turns**	**feet**	**turns**
	Single-band (very effective)			
3.5	22	8	20	6-8
7	22	10	15	6
10	12	10	10	7
14	10	4	8	8
21	8	6-8	6	8
28	6	6-8	4	6-8
	Multiband (good compromise)			
3.5-30	10	7	10	7
3.5-10	18	9-10	18	9-10
14-30	8	6-7	8	6-7

somewhat more expensive. Ideally the cable should be a close fit inside the ferrite sleeve, and this may not be easy to achieve with readily available materials.

The power rating of any choke balun is essentially that of the cable itself. Even if magnetic material is involved, the main feeder currents cancel inside the cable, leaving only the small residual surface current to magnetise the core.

Although choke baluns will prevent surface currents from flowing at the feedpoint itself, electromagnetic coupling between the antenna and points further down the feedline may induce surface currents, which the balun cannot prevent. This will happen if the installation is asymmetrical.

Induced currents become much greater if the feedline length is resonant, producing greater RF voltages on the line and on the equipment in the shack. The resonant length has to be measured from the feedpoint, down the coaxial cable, through the equipment in the shack, and away down to RF ground via various lengths and loops of wire and metal plumbing. There can be many additional loading effects, which alter the resonant length from its free-space value, so it can be very difficult to identify the exact causes of feedline resonance. If a choke-type balun fails to suppress feedline currents, the solution is to leave the balun there, and place further RF chokes, see Figs 11.18(a), (b) and (c), at intervals down the feedline to interrupt any resonant current distributions. A suitable interval would be a quarter-wavelength, or in a multiband system you could use pairs of chokes 2.5-3m apart, avoiding half-wave separations at any frequency in use.

Transformer or voltage baluns

A balanced antenna feedpoint will present an equal impedance from each side to ground. The accusation levelled at choke baluns is that they treat the symptom (the surface current I_3) without attempting to correct the imbalance that causes it. A transformer balun, on the other hand, does create equal and opposite RF voltages at its output terminals, relative to the grounded side of its input. This works fine in the laboratory; but up in the air where the balun is located, what exactly do we mean by 'grounded'?

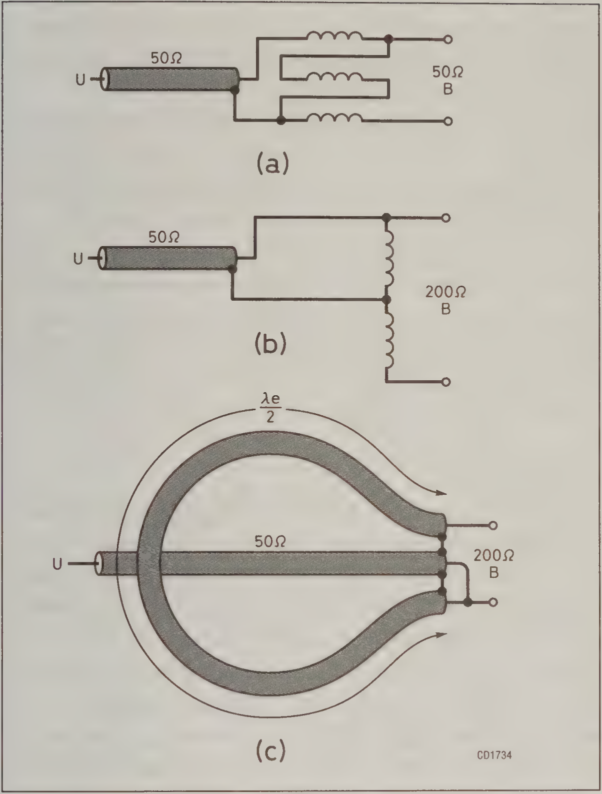


Fig 11.19: Transformer/voltage - type baluns. Windings shown separately are bifilar or trifliar wound, possibly on a ferrite rod or ring. (a) wire-wound 1:1 (trifliar). (b) Wire-wound 4:1 (biflar). (c) Coaxial 4:1balun only practical for the upper HF bands and VHF. The half-wavelength must allow for the velocity factor of the cable.

Voltage baluns may or may not involve a deliberate impedance transformation. You are probably familiar with the basic 1:1 and 4:1 baluns. **Fig 11.19** shows a wire-wound 1:1 balun, and both wire-wound and coaxial-cable versions of the 4:1 type. These all have the common property of forcing balance at their output terminals by means of closely coupled windings within the transformer itself. The 4:1 balun in Fig 11.19(b) is the easiest to understand. Typically, it transforms 50 ohms unbalanced to 4 x 50 = 200 ohms balanced.

This is achieved simply by a phase inversion. An applied voltage v at one side of the feedpoint is converted by the transformer action into a voltage -v at the other side. These two voltages 180° out of phase represent the balance we are seeking to achieve. The 4:1 impedance transformation arises as follows. If the original voltage on the feedline was v, the voltage difference between opposite sides of the feedpoint is now 2v. Since impedance is proportional to voltage squared, and $(2v)^2 = 4v^2$, the impedance is stepped up by a factor of 4.

In the wire-wound 4:1 balun shown in Fig 11.19(b), the 180° phase inversion is achieved by the connection of the windings, while the coaxial equivalent in Fig 11.19(c) does it by introducing an electrical half-wavelength of cable between opposite sides of the feedpoint. Strong coupling between the windings and inside the coax forces the whole system into balance.

However, if any balun is treated as a 'black box' and we look at the currents flowing in and out, it is apparent that any current difference between the two sides of the antenna has nowhere else to flow but down the outside of the coax. But that does not mean that the balun is no better than a direct connection; when you insert the balun, it forces the currents in the antenna to readjust and become more symmetrical. To make a meaningful evaluation of the effects of a balun, you therefore need to include the entire antenna and its surroundings in your analysis.

Any unbalanced antenna/feedline system will always 'push back' against an attempt to force it into symmetry. So although the transformer balun may do a good job, it still may not achieve total equality between the currents on opposite sides of the feed point. That may leave a residual difference current I_3 to flow down the outside of the coax, as noted above. Unfortunately, having made its effort to minimise that difference current, the transformer balun does nothing to prevent it from flowing onto the coax. And there is still the possibility of additional currents being induced further down the surface of the feedline. This implies that a transformer-type balun may require additional RF chokes at the balun itself and possibly further back down the line.

Which HF balun is best?

W7EL [4] has made some direct comparative tests between choke and transformer baluns in something approximating a real situation. The baluns were inserted between a horizontal 28MHZ dipole and a half-wavelength of coaxial feeder. Since the transmitter end of the feeder was well grounded, this feeder length presents a particularly low impedance to surface currents at the feedpoint, and places great demands on the balun. W7EL measured the currents in the dipole at both sides of the feedpoint, and also the imbalance current on the surface of the coax. He found that even minor physical asymmetry in the installation resulted in marked electrical asymmetry; and that both types of baluns produced improvements.

Many amateurs have found this for themselves. Whichever type of balun cures your particular problems (such as RF in the shack or EMC), it's good enough. However, in W7EL's experiments the choke balun produced consistently better improvements in balance than the transformer or voltage type. This is consistent with the lack of direct effort in the transformer balun to suppress feedline surface currents.

The PA0SE HF balun

This HF balun design, by Dick Rollema, PA0SE, [5] was the solution for feeding an all-band (7MHz to 29MHz) antenna. The feed impedance of this antenna ranged from 33 ohms on 7MHz to 560 ohms on 29MHz, and highly reactive, although balanced. This ruled out direct single-coax feed and also the use of ferrite or powdered iron in the baluns. Units with a 4:1 impedance ratio promised a better match to his 17m of RG217/U to the shack than 1:1 baluns, especially on the highest frequencies, where the coaxial cable feeder losses due to mismatch were highest.

The balun is made from coaxial cable as shown in **Fig 11.20(a)**. Two equal lengths are connected in parallel at their unbalanced left hand ends and in series at the balanced right hand ends. Let us assume that instantaneous HF voltage can be measured on the centre pin of the left hand coax connector and that this voltage is +100V with respect to earth. The result is +100V on the top balanced terminal and -100V on the bottom balanced terminal, i.e. 200V between them, balanced with respect to earth.

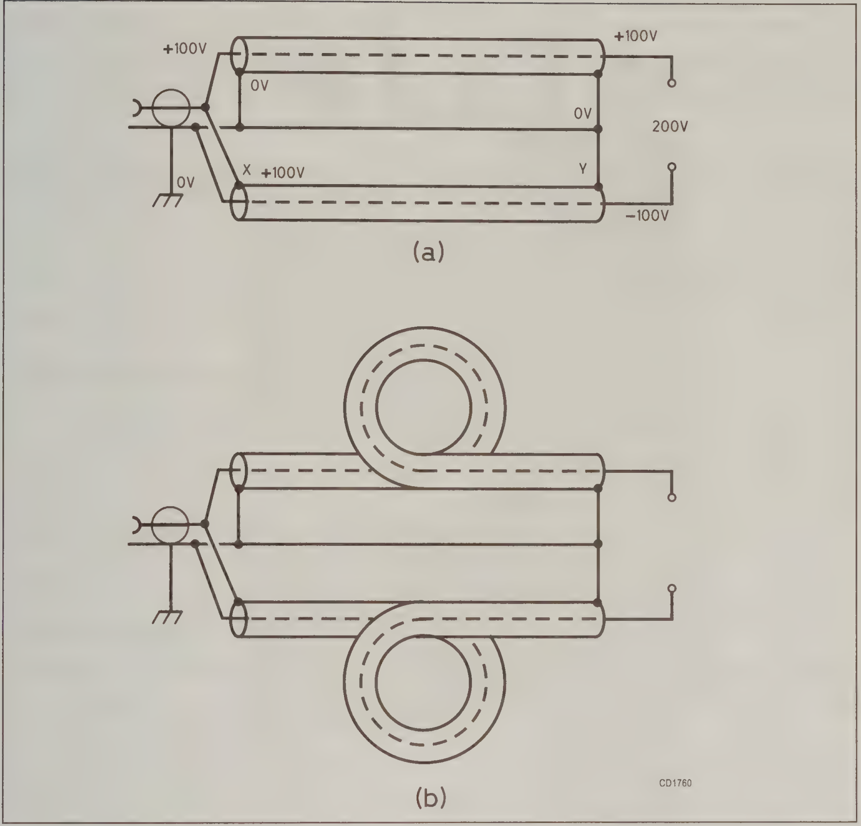


Fig 11.20: Principle of the 4:1 coax balun. Short-circuiting the voltage between X and Y in (a) is remedied by the self-inductance created by coiling the coax as in (b). The upper coax is coiled for neatness only.

However, with straight lengths of coax there would be a short-circuit between the +100V at point X and 0V at Y.

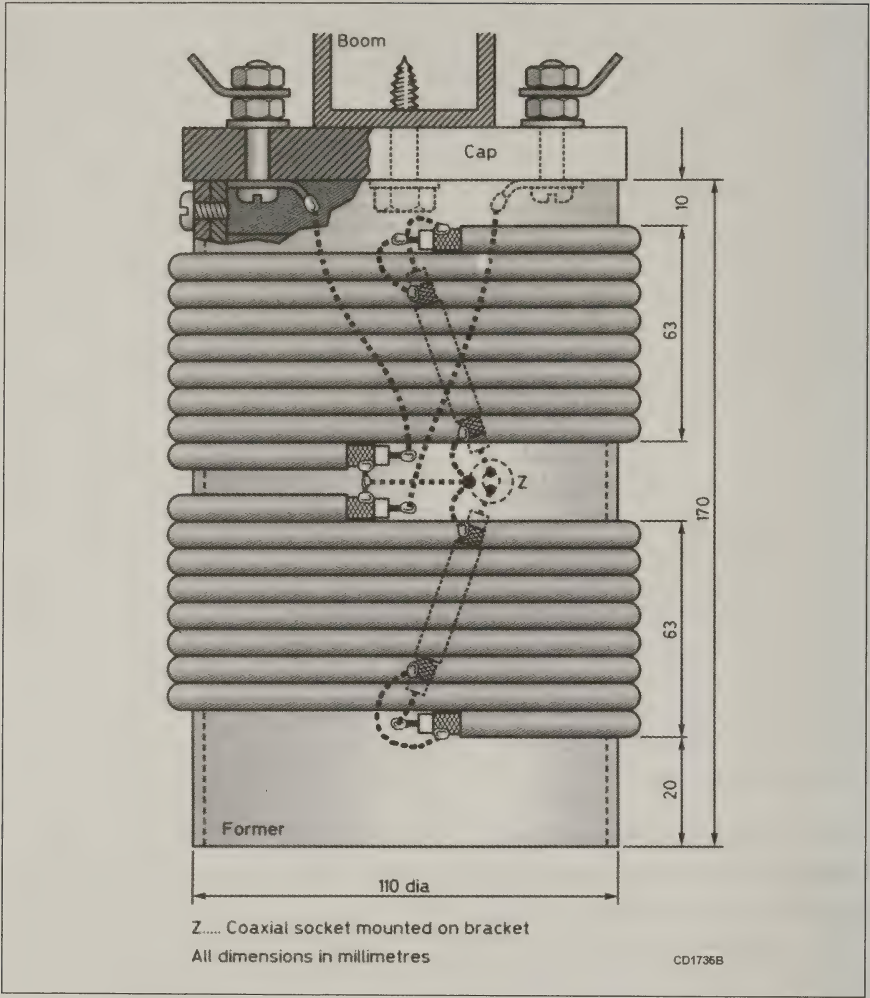
This short is eliminated by coiling the lower cable as shown in **Fig 11.20(b)**. Between X and Y there is now the reactance of that coil; if sufficiently high, point X no longer 'sees' point Y and there can be a voltage difference between them. For the top coax there is no such problem as both ends are at the same potential, but it is coiled for neatness.

This balun produces a 4:1 impedance transformation only if both cables are terminated in their characteristic impedance. PA0SE used 75ohm coax, so for 'flat' lines a purely resistive, balanced load of 2 x 75 = 150 ohms would be required. Looking into the unbalanced end of the balun, an impedance of 75/2 = 37.5 ohms would then be seen.

With most antennas the feed impedance is anything but 150 ohms resistive. Unless the length of the cables in the balun is short with respect to the wavelength, the balun produces an additional impedance transformation which is largest when the cable lengths are near λ/4. This can add to or subtract from the 4:1 ratio. In the extreme, the impedance at the unbalanced end can even be higher than that of the balanced load! But that does no harm; the balancing action is valid over the whole intended frequency and impedance range.

The balun assembly, with dimensions, is shown in **Fig 11.21**. None of these dimensions or the materials and cable types are critical. The former on the prototype was made of grey 110mm OD PVC waste pipe.

Fig 11.21: Construction of a 4:1 balun of 75Ω coax on a PVC former. The dashed connections are inside the former.


Boom
Cap
10
63
170
Z
63
20
Former
110 dia
Z..... Coaxial socket mounted on bracket
All dimensions in millimetres
CD1736B

PA0SE used matching end caps for the balanced ends; these are not cemented on, but made removable by securing them with three self-tapping stainless steel screws. An N-socket (not shown) on a copper bracket is mounted inside the former for connection to the RG213/U coax feeder at point Z. N-connectors are waterproof by design and, additionally, are sheltered by the former.

On the prototype, off-cuts from a 75-ohm cable TV installation, whose specification is similar to Uniradio M203, was used.

The Balun is made from two equal lengths of cable wound into the two 8-turn coils (note the winding direction). They are held in place by the ends of the bare-wire jumpers, which protrude through snug-fit holes in the former.

At the balanced end of the coils the braids are joined and connected to the N-socket outer, via a bare wire jumper. The centre conductors are connected to the balanced terminals using bare wire jumpers (shown with dotted lines). The unbalanced outer ends of the coax coils are connected by short lengths of coax inside the former to the N-socket.

Note that the inside conductor of the coax link is connected to the top coil braid and the braid to the inner conductor (on the top coil only).

All coax ends, solder connections and feed-through holes were fixed and waterproofed with epoxy cement. Three coats of clear yacht varnish protect the completed assembly against ultra-violet light. After four years use, the baluns are as good as new.

MATCHING ANTENNAS TO TRANSMISSION LINES

Wire HF antennas are often used with an Antenna Tuning Unit, described in detail in Chapter 4. Another method is to use a matching arrangement at the antenna, particularly with beam antennas. Some of the more popular matching arrangements are described below.

The direct connection

The halfwave dipole has a theoretical centre feedpoint impedance of 75ohms at resonance. In practice this value is less, particularly at HF, because of the presence of ground. Generally the centre of a dipole can be connected directly to 50-ohm coax cable as shown in Chapter 2 and will almost always provide a good match. A current balun, described earlier, may be necessary at higher transmitter powers.

The folded dipole

A halfwave antenna that is used as the driven element will normally have a feedpoint impedance much lower that 50 ohms. In this case some impedance transformation is required.

A transformer can be used to step the antenna impedance up to the correct value but this can have the effect of reducing the bandwidth. It has been found that by folding the antenna a 4:1impedance step-up can often be accomplished with an increase in impedance bandwidth.

Other ratios of transformation than four can be obtained by using different conductor diameters for the elements of the radiator. When this is done, the spacing between the conductors is important and can be varied to alter the transformation ratio. The relative size and spacing can be determined with the aid of the nomogram in **Fig 11.22**.

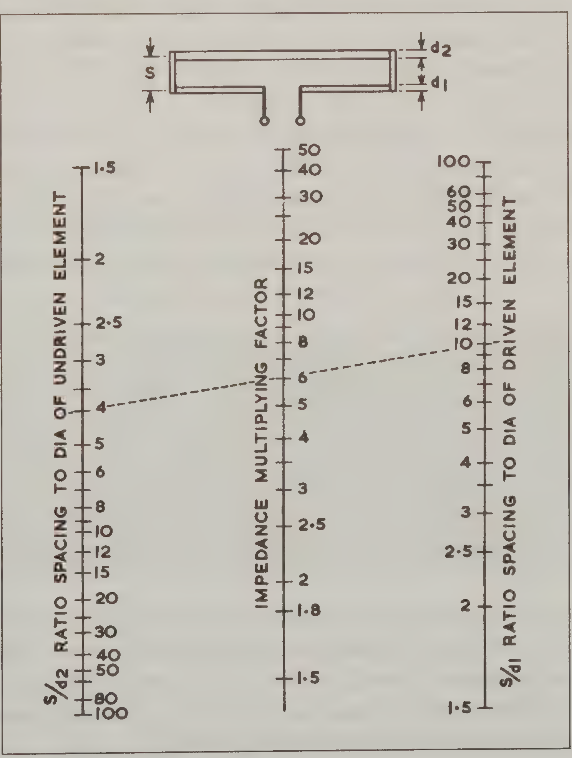


Fig 11.22: A nomogram for folded dipole impedance ratio calculations. A ruler laid across the scales will give pairs of spacing / diameter ratio for any required multiplier. In the example shown the driven element diameter is one-tenth of the spacing and the other element diameter is one-quarter of the spacing, resulting in a setup of 6:1. There are unlimited solutions for a given ratio.

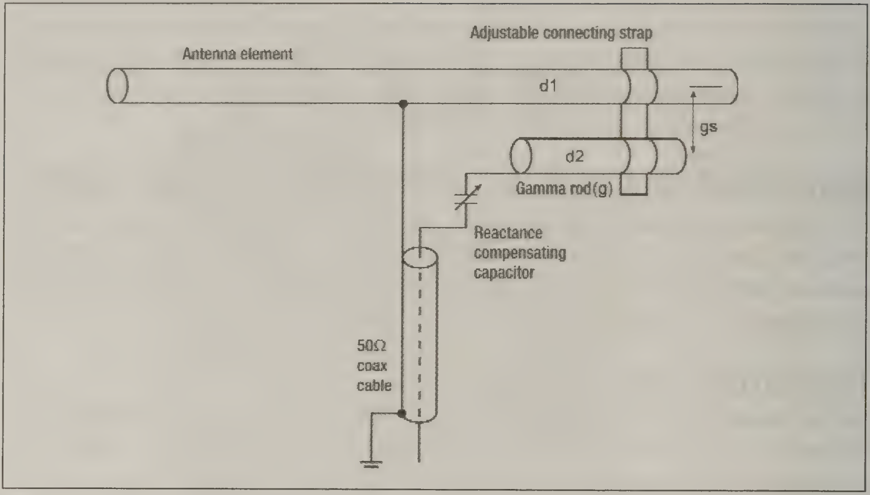


Fig.11.23: Diagram of a Gamma match. Matching is achieved by altering the position of the gamma rod adjustable connecting strap point on the antenna element. The series capacitor C also has to be adjusted to cancel the inductance of the gamma rod. See Table 11.2 for parameter values.

The Gamma match

The Gamma match is an unbalanced feed system suitable for matching coax transmission line to the driven element of a beam. Because it is well suited to plumber's delight construction, where all the metal parts are electrically and mechanically connected to the boom, it has become quite popular for amateur arrays.

A short length of conductor (often known as the Gamma rod) is used to connect the centre of the coax to the correct impedance point on the antenna element. The reactance of the matching section can be cancelled either by shortening the antenna element appropriately or by using the resonant antenna element length and installing a series capacitor C, as shown in **Fig 11.23**.

Because of the many variable factors - driven-element length, Gamma rod length, rod diameter, spacing between rod and driven element, and value of series capacitors - a number of combinations will provide the desired match. The task of finding a proper combination can sometimes be tedious because the settings are interrelated. The exact Gamma dimensions and value for the capacitor will depend on the radiation resistance of the driven element, and whether or not it is resonant. The starting-point dimensions given in **Table 11.2** are for

Frequency	Gamma rod length (g)	Spacing (gs)	Gamma C1	Omega C2
14MHz	1.22m (48in)	152mm (6in)	140pF	15pF
18.1MHz	1.0m (39in)	140mm (5.5in)	125pF	20pF
21MHz	0.92m (36in)	128mm (5in)	100pF	20pF
24.9MHz	0.75m (30in)	114mm (4.5in)	87pF	25pF
28MHz	0.60m (24in)	100mm (4in)	75pF	25pF

Table 11.2: Gamma and Omega match dimensions and capacitor values. The capacitor values relate to the maximum value of a variable capacitor, in practice the final value after adjustment will be lower. The lengths of (g) and (gs) are maximum values, in practice they could be up to 20% less. Length (g) on an Omega match is 50% shorter than shown.

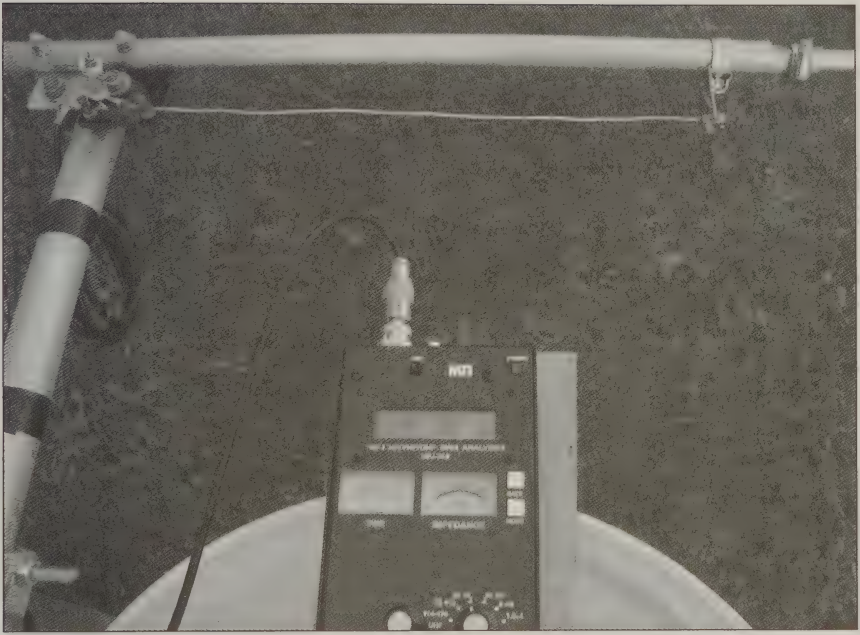


Fig 11.24: A Gamma match for 50MHz during the matching phase. It uses hard drawn copper wire as the Gamma rod. The connection to the antenna element is achieved using a hose clamp.

an array having a feed-point impedance of about 25 ohms, with the driven element shortened approximately 3% from resonance.

After installation of the antenna, the proper constants for the Gamma generally must he determined experimentally. The use of the variable series capacitor, as shown in Fig 11.23, is recommended for ease of adjustment. With a trial position of the tap or taps on the antenna, measure the SWR on the transmission line and adjust C1 for minimum SWR. If it is not close to 1:1, try another tap position and repeat.

The Gamma rod is normally made from thin aluminium tube whose diameter recommended in most publications is 1/3 to 1/6th of the antenna element diameter. However, it is worth trying what is to hand. A simplified Gamma match can be made using hard drawn copper wire as the Gamma rod, whose connection to the antenna element is achieved using a hose clamp as shown in **Fig 11.24**.

The traditional method of Gamma capacitor is to use an air-spaced variable capacitor and enclose it in a weatherproof metal box. Corrosion to the capacitor can still occur because of condensation. When the Gamma match is adjusted for the lowest SWR the value of the variable capacitor can then measured and a fixed capacitor (or several series/parallel combinations) substituted. This arrangement will handle 100 watts without breakdown and requires only a smear of grease to achieve weatherproofing .

The Omega match

The Omega match is a slightly modified form of the Gamma match. In addition to the series capacitor, a shunt capacitor is used to aid in cancelling a portion of the inductive reactance introduced by the Gamma section. This is shown in **Fig 11.25**. Cl is the usual series capacitor. The addition of C2 makes it possible to use a shorter Gamma rod, and makes it easier to obtain the desired match when

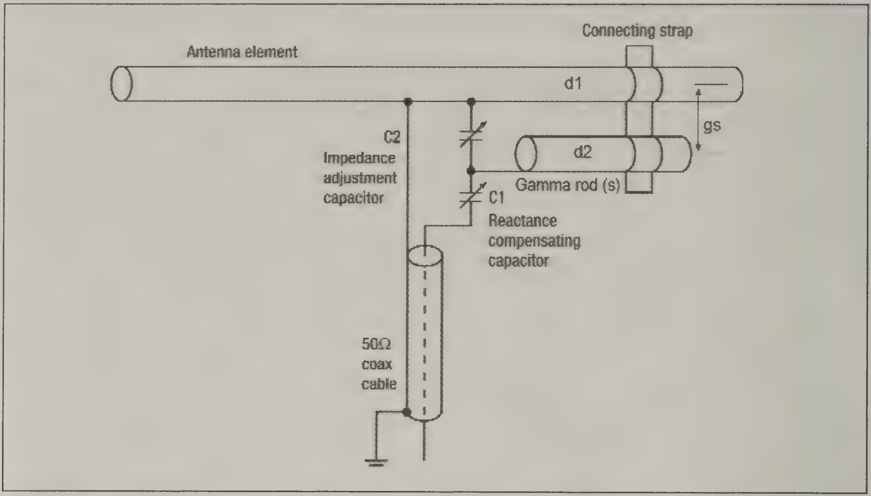


Fig.11.25: Diagram of an Omega match. Matching is achieved by adjusting the parallel capacitor C2 and the series capacitor C1. See Table 11.2 for parameter values.

the driven element is resonant. During adjustment, C2 will serve primarily to determine the resistive component of the load as seen by the coax line, and C1 serves to cancel any reactance. Fixed capacitors can be used to replace the variable ones once the matching procedure is complete. In general the dimensions are the same as for the Gamma match but the Gamma rod can be shortened up to 50%. The maximum value of C2 is approximately 1.4pF per metre of the operating frequency.

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[1] 'Fitting coaxial connections', Roger Blackwell, G4PMK, *RadCom* May 1988.
[2] ‘In Practice’, Ian White, G3SEK, *Radcom* June 1998.
[3] 'Balanced to unbalanced transformers', Ian White, G3SEK, *RadCom* December 1989.
[4] 'Baluns: what they do and how they do it', Roy W Lewallen, W7EL, *ARRL Antenna Book*. (W7EL coined the term 'current balun' for the type described in this article as a choke balun, and 'voltage balun' for the transformer type.)
[5] ‘Eurotek’, Erwin David, G4LQI, *Radcom* August 1992.

12

Estimating and measuring performance

The most important question that you will ask yourself after you have constructed a new antenna is just how well does it work? And if you find that it is not performing very well how do you check for problems? Some items of test equipment are useful for testing the antennas. It doesn't have to be expensive and it makes the business of tuning and optimising the antenna easier and more interesting. First of all I will describe some of items of test equipment and later on in the chapter show how it may be used to optimise antenna performance.

THE SWR METER

The most basic of all items of antenna test equipment for testing and if necessarily adjusting antenna matching or ATU tuning is the reflectometer SWR meter. These instruments are cheap to buy and easy to use. Even CB SWR meters work quite well in the amateur bands, but if you want to make one see Chapter 4.

You can check the calibration of an SWR meter quite easily. Terminate the antenna connector on the SWR meter with a 50 ohm non-inductive resistor or a 50 ohm dummy load. Feed in a small amount of power into the Transmitter connector and the SWR should read 1:1. Repeat with a 25 and a 100 ohm resistor and the reading should be 2:1 for both these resistors. You can check the SWR meter with any value resistor between 10 and 250 ohms. If the test resistor value

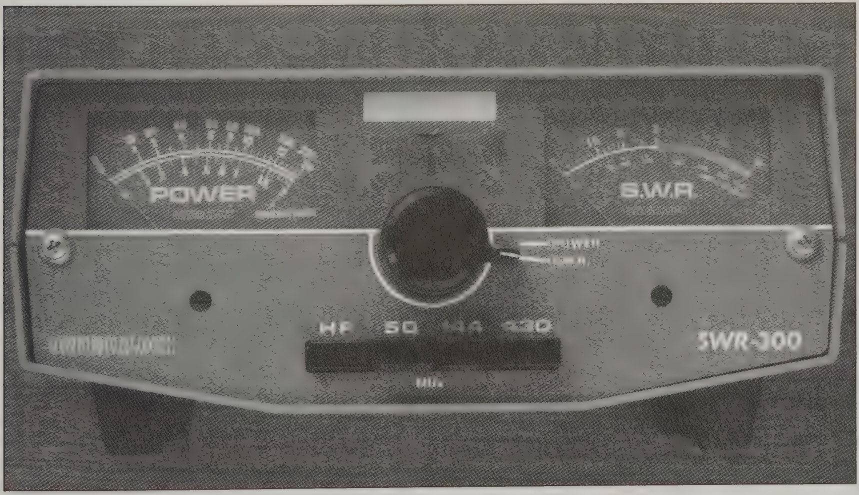
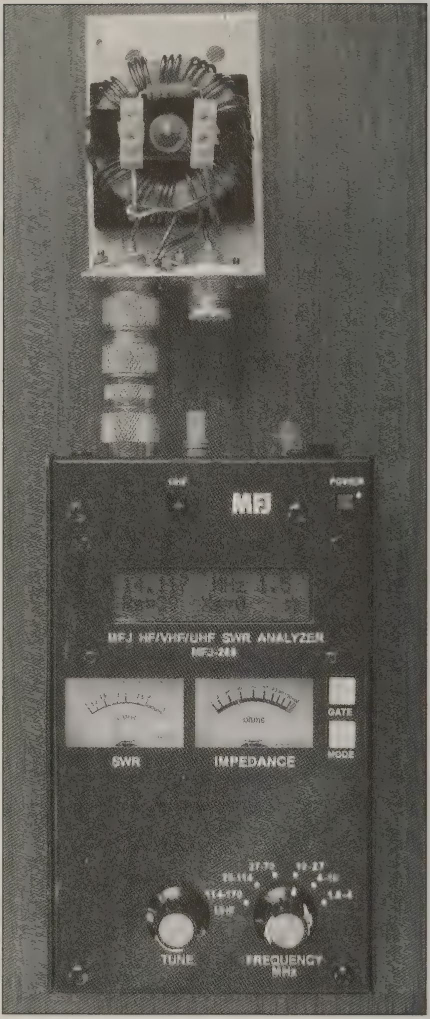


Fig 12.1:The SWR reflectometer

Fig 12.2: MFJ-269 being used to check the performance of a home made balun



is below 50 ohms, just divide its value into 50 to get the SWR reading. If the test resistor is above 50 ohms just divide its value by 50. All the foregoing assumes that the SWR meter is designed for 50 ohms.

These measurements should be done using a transmitter or transceiver with a variable power output control. Use only enough power to make the measurements. Use test resistors that are capable of taking the power, although you can get away with low power resistors if you make very short duration transmissions. If the resistors get hot then the resistance value may change, upsetting the calibration check.

A better way is to use one of the SWR analysers available today, such as the MFJ259/269. If you read the Instruction Manual of the MFJ-269 you will learn a lot about antennas and transmission lines.

A low SWR does not mean that the antenna is performing well. In fact you can use the SWR meter to measure the quality of coax feeder; see Chapter 11.

THE DIP-OSCILLATOR (GDO)

The Dip Oscillator is an instrument for measuring the resonance of a tuned circuit or an antenna element without the need of a direct connection. RF power from a calibrated tuneable oscillator is absorbed by the circuit under test when it and the oscillator are tuned to the same frequency. A meter is used to give an indication of oscillator energy loss. The instrument is more commonly known as a GDO (Grid Dip Oscillator) from the time when it used a valve or electronic tube as the active device. The meter was normally connected in the grid of this device and it indirectly measured RF oscillator level. Resonance was indicated by a dip in the meter reading, hence Grid Dip Oscillator. Although this instrument now uses a bi-polar transistor or an FET as the active element of the oscillator I will refer to it as a GDO because this is abbreviation it is mostly known by.

The traditional GDO uses plug-in coils, which are used to select the frequency band of the oscillator and to couple the instrument to the circuit under test. While coupling the GDO to a tuned circuit is easy, coupling to a length of wire

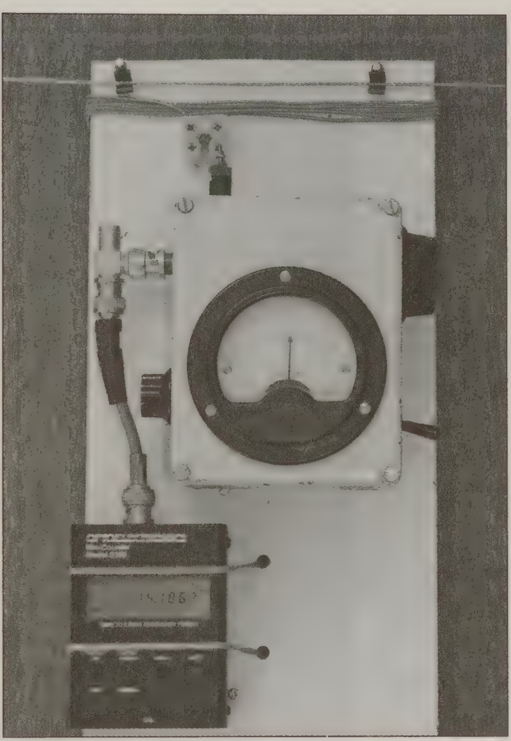


Fig 12.3: Element resonant frequency measuring unit MkVI shown measuring the frequency of an uninsulated wire antenna element.

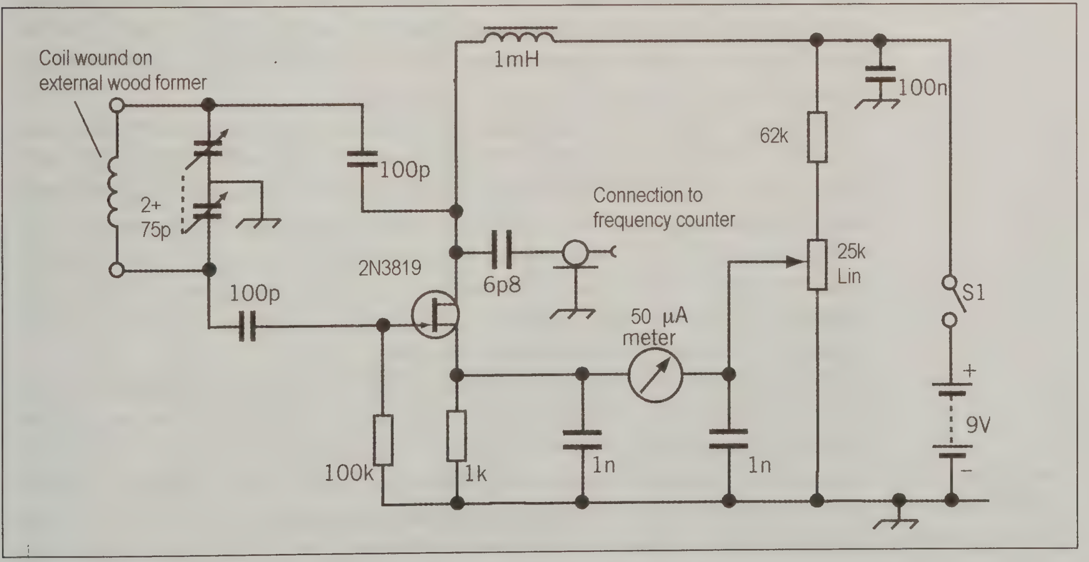
or aluminium is not. The solution is to wind the oscillator coil on a former that has a long flat side that can be laid along the antenna element under test.

The traditional GDO used a frequency dial, calibrated against the plug-in coils. These days the instrument is normally used with a frequency counter so the dial is not required.

The instrument shown in **Fig 12.3** is designed specifically for measuring the resonance of antenna elements and can be constructed from junk box components. It has a large sensitive 50µA meter for indicating the dip. The frequency control is consigned to the side of the unit because a dial is not required.

The circuit is a simplified version of the Colpitts circuit and is shown in **Fig 12.4**. Unlike most traditional GDOs this circuit does not measure gate current directly. What it does do is to measure the total current through the FET. This current depends on the gate voltage, which in turn depends on the oscillation amplitude. However, the variation of current through resonance is only a small part of the total current through the FET. To enable this small variation to be seen the 50µA meter is offset using a potentiometer in a bleeder network. This

Fig 12.4: Circuit of the GDO section of the Element Resonant Frequency Measuring Unit.



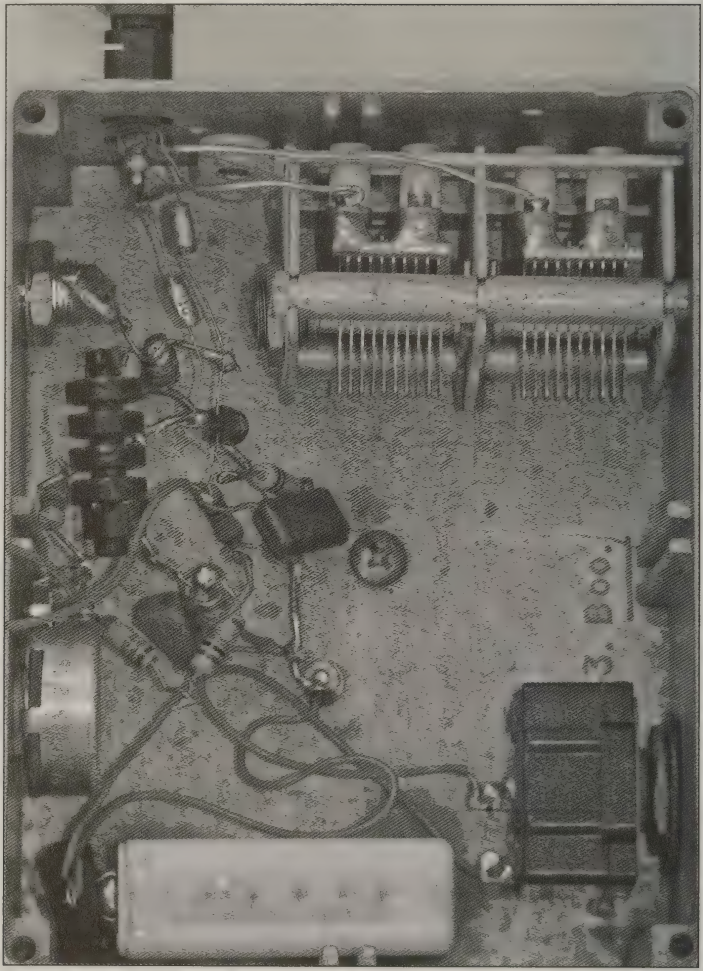


Fig 12.5: The layout of the GDO section of the Element Resonant Frequency Measuring Unit, constructed from junk box components.

is set so that the meter reads about 50% FSD when the instrument is not coupled to a load. If you find that adjusting the meter to this value is too critical for your liking use a lower resistance potentiometer or/and a larger value of the 62k bleeder resistor.The layout is shown in **Fig 12.5**.

The GDO is fixed to a laminated chip board 150mm wide x 15mm thick, which provides support for the GDO, frequency counter and coil. The coil comprising five turns of 20SWG plastic insulated wire is wound on to this board. This makes up a rectangular section coil that gives a very good coupling to a wire or tubular antenna element and has an inductance of around 3μH. With the capacitor used in this model it tunes from 12MHz to just over 22MHz, just enough to cover the 20, 17 and 15metre bands. The frequency range can be extended by shorting out or adding coil turns.

The coupling between the instrument and the antenna element has to be held constant while making a measurement, which can be difficult if you are perched on top of a step ladder. To make this easier two small plastic cable wall clips are fixed to the board as shown in Fig 12.3. The wire antenna element is placed inside these two inverted clips so that the distance between it and the coil is held constant, which makes the business of measuring the element resonance much simpler. Resonant dips of 30 to 40% of the meter FSD are possible with this arrangement.

To measure the resonance of a tubular element the instrument coil is place on top of the element. A method of fixing the distance between the element and the coil is unnecessary in this case.

THE FIELD STRENGTH METER (FSM)

The normal way of checking out the new antenna that you have just bought or constructed is to just fire up the transceiver into it, having first determined that the SWR is reasonably low. You then spend some time obtaining reports on both transmit and receive, where possible comparing it with some previous or existing antenna. Such methods are affected by QSB, nevertheless, over a period of time you can get quite a good statistical series of S meter measurements. A more instant method of obtaining an idea of antenna performance is to use a Field Strength Meter (FSM) to make local field strength readings. A FSM can be used to:

- Make comparative measurements of various antennas to assess relative gain
- Plot a polar diagram to record antenna directivity.
- Enable a transmitter antenna to be tuned for maximum efficiency or gain.
- Locating the source and measuring the level of radio interference.

Diode FSM

This instrument also goes by the name of the Absorption Wavemeter, which has a calibrated frequency dial and switched, or plug-in coils. In the early days of amateur radio it was a condition of the licence that you had one of these in the shack to measure frequency and the relative strength of harmonics.

These days such an instrument is redundant for this purpose but it can be used as an indicator to maximise radiated power when tuning an antenna or ATU. You can construct one of these instruments very easily; the circuit is shown in **Fig 12.6**. Sensitivity is set by the size of the antenna; a short telescopic whip is useful for achieving this.

The tuned circuit does not need to be calibrated. A 140pF capacitor will tune 2.5 to 8MHz with 24turns wound on a 40mm plastic former. Other frequency ranges can be achieved using taps to short out turns on the coil.

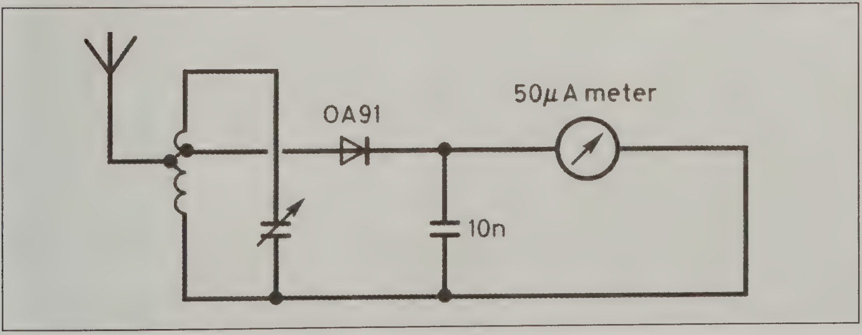


Fig 12.6: A simple tuned diode field strength meter.

The communications receiver as an FSM

Every radio shack has an FSM in the form of a receiver or transceiver. On the face of it the modern transceiver should make good field strength meter. Many are small and portable and convenient to use. In practice a receiver requires the RF gain be turned to maximum for the S meter to function correctly. Under these circumstances the receiver is very sensitive and a variable attenuator may be necessary for adjusting the signal strengths so that they fall in a useful region of the S-meter range.

So just what is a useful range? We should not expect different receivers to give the same S-meter reading of a given signal level on a given frequency unless by coincidence. This is because the gain distribution of each receiver stage is different for a specified design and the S-meter is normally activated from the AGC line. Some years ago at least one receiver manufacturer attempted to standardise S-meter readings so that S9 was equivalent of 50µV and the signal level between each S unit was 6dB, with scale above S9 calibrated in dB relative to S9. Icom have got quite close to this standard. On the IC-7400, S9 is equivalent to 50µV and the signal level between every S unit is 3dB.

You can check out your S-meter calibration by using a signal generator as shown in **Fig 12.7**. Many transceivers and receivers have S-meters comprising a bargraph indicator, which results in some loss in resolution, particularly noticeable at the high end of the scale. A conventional S-meter is preferred because of the higher resolution when measuring a change in signal strength.

Note that if you use an attenuator with a transceiver, disconnect the microphone to prevent the attenuator being burned out by an accidental transmission.

If the attenuator calibration requirement is not critical a carbon, or better still a Cermet potentiometer will make a useful variable signal strength attenuator. Two or more potentiometers can be cascaded for higher attenuation but they will

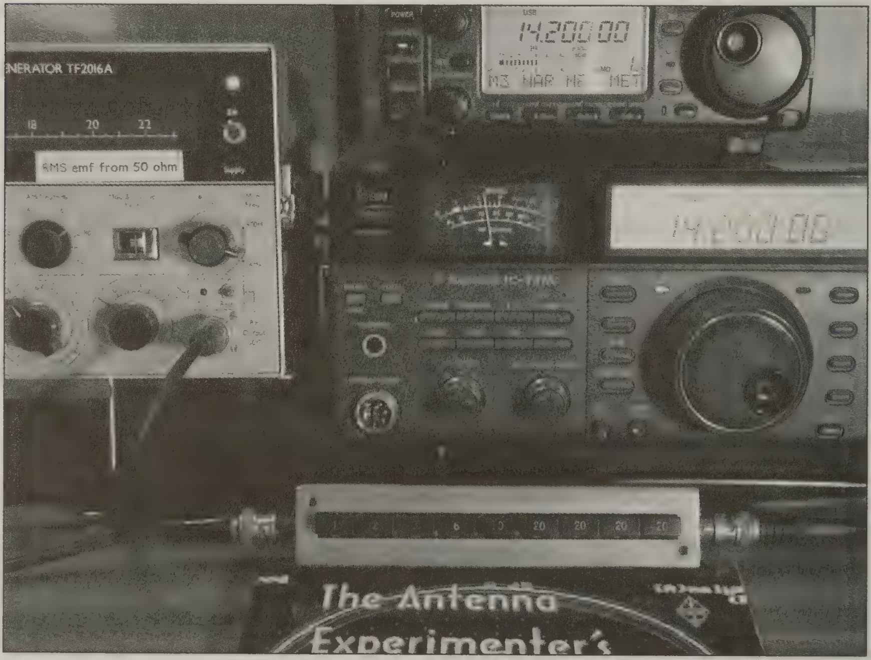
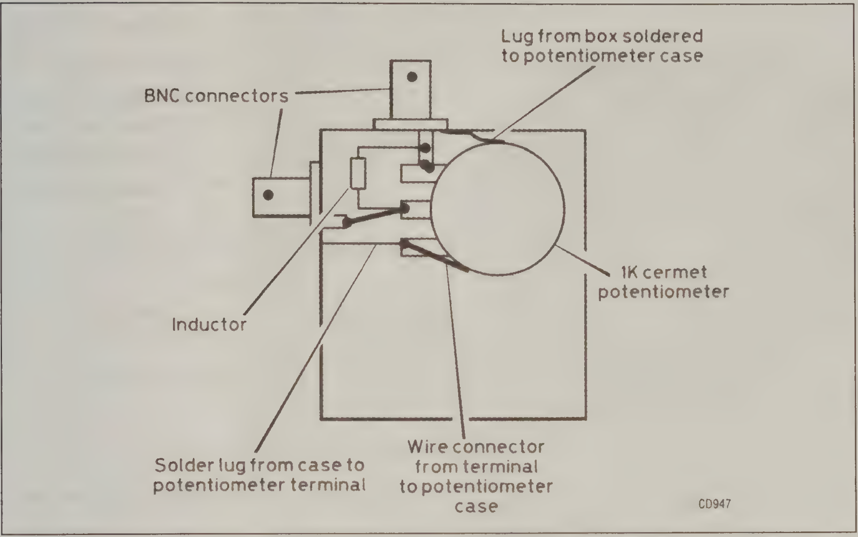
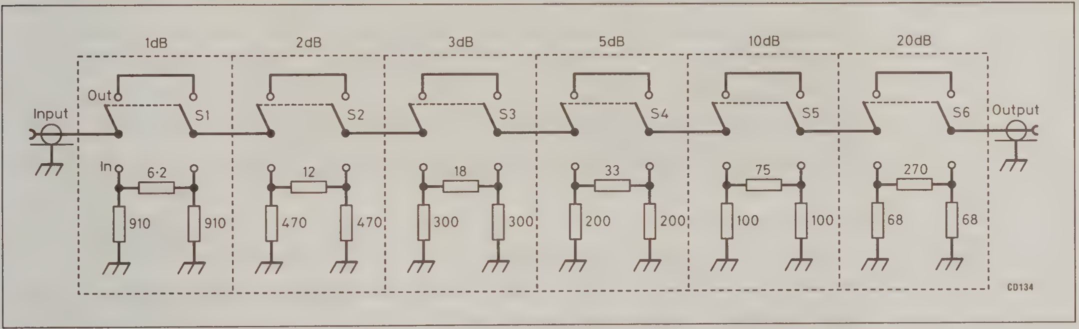


Fig 12.7: Test set up with a signal generator and a calibrated dB switched attenuator. The IC-737A uses a conventional S-meter while the IC-706 uses the bargraph type. Normally the receivers would be tested separately.


Lug from box soldered to potentiometer case
BNC connectors
Inductor
1K cermet potentiometer
Solder lug from case to potentiometer terminal
Wire connector from terminal to potentiometer case
CD947

(left) Fig 12.8: Variable attenuator constructed from a cermet potentiometer.

(below) Fig 12.9: Switched attenuator with six pi-network attenuators to give a maximum of 41dB attenuation in 1dB steps.



have to be constructed in sealed shielded box. The arrangement shown in **Fig 12.8** can be roughly calibrated for HF or the low VHF bands.

A switched attenuator shown in **Fig 12.9** is designed specially for performing gain measurements using a receiver or an uncalibrated field strength meter. It comprises eight pi-network attenuators to give a maximum of 41dB attenuation in 1dB steps.

The attenuator can be built into a die-cast box with screens between the switched sections, or a complete enclosure can be constructed from double-sided printed circuit board.

THE CLIP-ON RF CURRENT METER

The clip-on RF current meter has a long history but early versions involved breaking a ferrite ring into two equal pieces, which takes some doing. A constructional innovation by G0SNO was to use a large split ferrite bead intended for RF interference suppression. This clamps around the conductor under test, to form the one-turn primary of a wideband current transformer. The secondary winding is about 10 turns, and is connected to a load resistor, R1-R2, and the diode detector.

The load resistor, R1-R2, is important because it creates a low series impedance when the current transformer is effectively inserted into the conductor

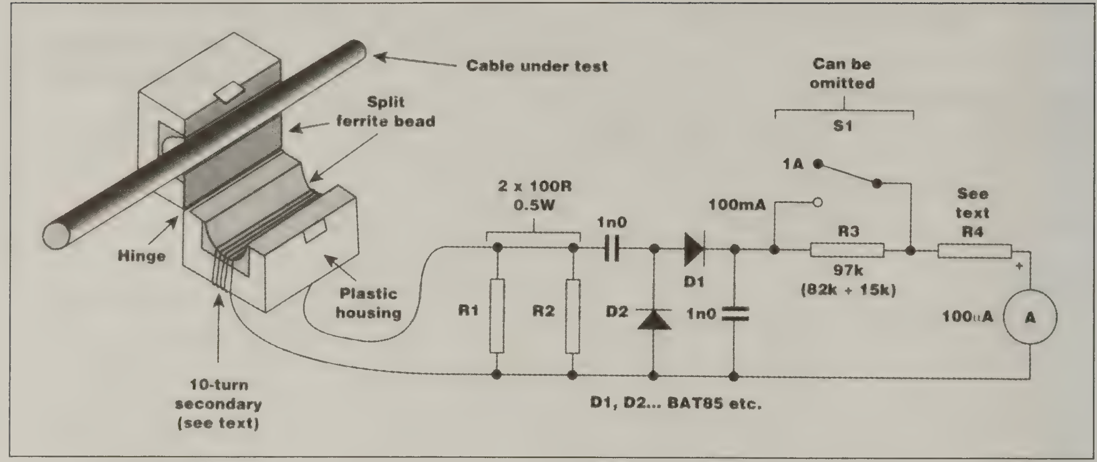


Fig 12.10: The clip-on RF current meter by G0SNO.

under test. For the values shown in **Fig 12.10** the 10-turn secondary and the two paralleled 100Ω results in (50/102 =) 0.5Ω. If the instrument is to be used for detecting low currents, and the high insertion impedance is not an issue (such as measuring and comparing antenna radial currents), this resistor can be omitted.

Component types and values are critical only if you want to make a fully calibrated meter with switchable current ranges. However, for a first try, and for most general RFI investigations, the meter is almost as useful without any need for calibration. Simply make R4 about 4.7-10kΩ, and omit R3 and SI. If the meter is either too sensitive or not sensitive enough, either change R4 or change the RF power level.

Just about any split ferrite core intended for RFI suppression will do the job, but there are a few practical points. Choose a large core, typically with a 13mm diameter hole. This allows you to clip the core onto large coax, mains and other multi-core cables while still leaving enough space for the secondary winding (which should be made using very thin enamelled or other insulated wire). It is important that the core closes with no air gap - and that can be a problem. A major disadvantage of the basic split ferrite core in its plastic housing (Fig 12.10) is that the housing is not meant to be repeatedly opened and closed, so the hinge may soon break. The classic way of making a fixing for the two halves of the clamp was to use a clothes-peg but a giant plastic paper-clip could be a better solution.

The only requirement about the clip is that it must be basically non-metallic, and that it can hold the two halves of the core accurately together while performing the measurement. It is vital that the two halves of the core are glued to the clip in such a way that they always close tightly together with no air gap. Hint: glue one half of the core to one side of the clip first, and let that side set; don't try to glue the second half until the first is good and solid.

Commercial current meter

The MFJ-845 clip-on current meter shown in **Fig 12.11** is a very similar design to that shown in Fig 12.10. The only difference is that it has additional switched ranges. It also uses an operational amplifier on the lowest very sensitive range (<30mA).

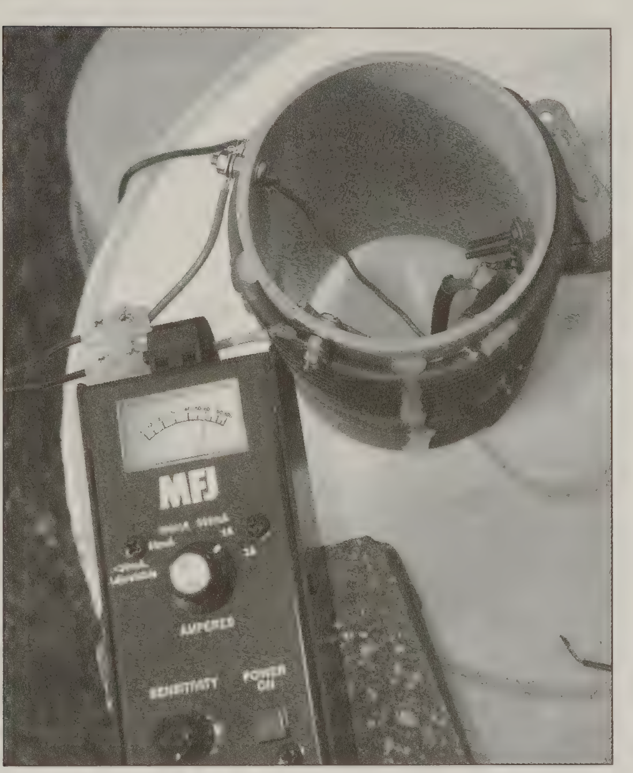


Fig 12.11: The MFJ-845 clip-on current meter being used to check the balance on the output of a coaxial balun.

OPTIMISING THE ANTENNA

Matching and SWR

To start with, it is essential that antenna and the feeder is matched to the transceiver. Most modern transceivers will not supply full RF power on transmit unless this condition is met. The signals on receive are much better when the antenna is correctly matched.

Methods of matching the feeder to the antenna have already been discussed in earlier chapter. The resonant dipole is probably the simplest of all antennas (see Chapter 1). The impedance at the centre of a half wave dipole is around 50 ohms and provides a close match to 50-ohm coax cable without any impedance matching networks. Matching (adjusting for minimum SWR) is achieved by altering the length of the dipole.

Often, design data (and that includes the dipole data in the Appendix) does not include the extra length of wire that may be needed to fix it to the insulator. One method of making a wire element adjustable is to make the element longer than specified and to fold the excess wire down along the element. In this way the elements can be made adjustable. The excess wire can be taped back along the element away from the insulator and may be trimmed when the adjustments are completed, as shown in Chapter 2.

The SWR meter, described at the beginning of this chapter, is connected in the feedline between the transceiver and the antenna to measure this standing wave. If the SWR is plotted over a range of frequencies as shown in **Fig 12.12** it can indicate certain interesting characteristics of the antenna and the feeder.

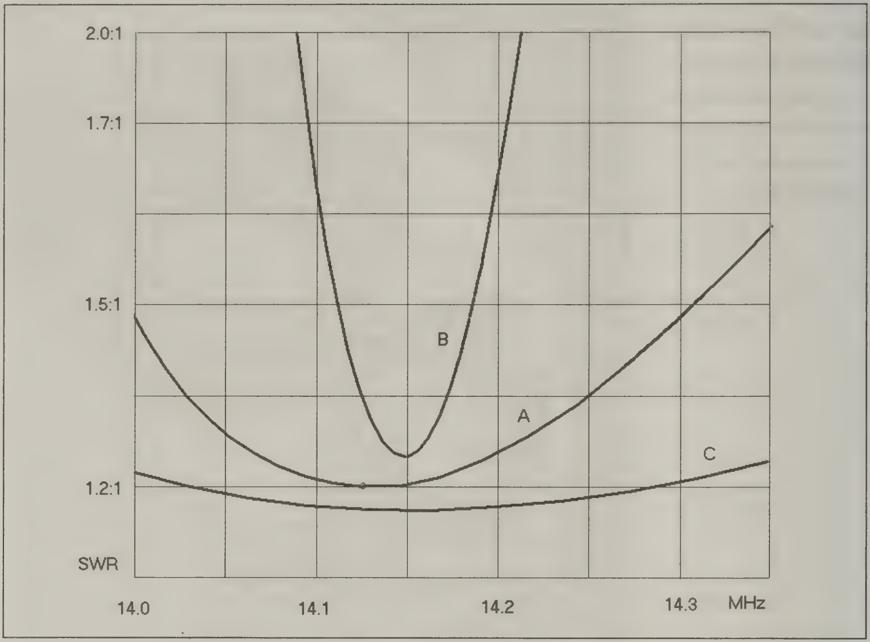


Fig 12.12: (A) SWR curve of a 14MHz dipole. (B) SWR curve of a mobile antenna. (C) SWR curve of a 14MHz dipole with apparent losses in the coaxial cable.

The impedance bandwidth of an antenna is defined as the frequency range over which the antenna impedance results in a SWR less than some arbitrary limit. This may be typically 1.5:1 for amateur operation with solid-state transmitters. The SWR plot or curve for a 14MHz dipole is shown in plot A of **Fig 12.12**.

Electrically small antennas for HF with loading inductors tend to give narrow impedance bandwidths ie the SWR varies sharply with frequency as shown in plot B of Fig 12.12. This does not mean that the antenna performance is poor. A narrow impedance bandwith means that the Q of the antenna is high but you may have to use some method of tuning the antenna if you want to cover all of the band.

A very flat SWR curve, as shown in plot C, might mean that the coax cable is very lossy. A low SWR does not necessarily mean that the antenna is performing well. In fact you can use the SWR meter to measure the quality of coax feeder; see Chapter 11.

Listening tests

If you already have an existing antenna whose performance you are already familiar with, you have a good reference point. Initial tests can be done on receive by listening to the signal strengths of various stations on first one, then the other antenna. A coaxial switch is beneficial in this situation, allowing you to switch quickly between antennas and be ahead of propagation fading. It is always useful to have a notebook where all these notes of the comparisons between antennas can be jotted down. Don't use scraps of paper - they soon get lost.

If you are operating from a new location with a new antenna it will take time to know how your antenna is performing because you are also checking the performance of your new location.

HF beam antenna optimisation

All installations benefit from some tuning, and most well known DX operators have spent a considerable amount of time adjusting the antenna for maximum efficiency, particularly when a new antenna is constructed. It is almost impossible to get complete reproducibility of any design. All installations are located in different environments, made of slightly different materials and situated at different heights. For example, if you use bare copper wire instead of plastic insulated wire for wire elements it will be necessary to multiply the wire dimension figures, given in the design data on any wire antenna by 1.04. Plastic covered wire appears to have a velocity factor of about 0.96. Try measuring the resonance of two identical lengths of wire, one with insulation and the other without to check this. Use the GDO element resonance instrument described earlier in this chapter.

If the performance of an antenna is not optimised a promising new design can be prematurely abandoned because of an unwarranted inferior performance.

Ideally, the antenna should be adjusted in situ. In the case of a VHF antenna it may be adjusted at a height of two or three wavelength without any difficulty and there will be very little change when it is raised to 10 wavelengths. Adjusting an HF antenna in situ is only possible if the antenna is mounted on top of a flat roof or on a fixed tower with a working platform at the top of it, with the antenna element lengths and feeder matching adjustments easily accessible.

Before an antenna is adjusted, ensure that the dimensions of the elements and spacings are correct, either by checking the lengths with available design data. If you are working with a new design adjust the driven element to the resonant frequency, the reflector to 5% lower than resonance and directors 5% higher as a starting point. Resonance can be measured using the GDO measuring instrument described earlier

When measuring the driven element resonance disconnect the feeder and short the feedpoint. When the feeder cable is connected it may cause many very deep false resonances if the feeder is not terminated correctly.

Elements made of different diameter telescoped aluminium tubes clamped with hose clamps are easy to adjust. Just loosen the clamp and slide the tube to the required length. It is a good idea to make a mark on one of the tubes to provide a reference in case you find it necessary to return to this point during the adjustments.

GROUND-WAVE TESTS WITH ANOTHER STATION

One of the most frequently used and reliable methods of testing an antenna is with another station some distance away, say 2 to 3km (1 to 2 miles). In these tests the station receiver is being used as a signal strength meter as described earlier in this chapter. With your receiver connected to the AUT (antenna under test) the signal strength of the local station can be monitored as the AUT is rotated. These signal levels can be plotted against antenna direction to provide a fairly comprehensive directivity pattern.

Some consider these tests as invalid. This is because the azimuth polar diagram of an antenna at an elevation angle of zero degrees on a computer simulation program gives an error message saying that there is no field to plot at zero degrees. A nearby station, a couple of kilometres away would looking at your antenna at zero elevation angle and would, according to the simulation program, not receive any signal.

Nevertheless ground wave tests with another station really do work because a computer (mathematical) model is a simplification of the real world.

The disadvantage of this method is that the station transmitter will have to radiate a fairly large signal, which can cause QRM to other users. A further disadvantage of this method is that the procedure for making the measurements is a bit cumbersome with another station being involved. It would be more advantageous to have access to the AUT, the signal source and the receive antenna, particularly if you are making constant adjustments to the antenna in an effort to obtain maximum performance.

If you have enough space these tests can be done at a closer range using low transmitter power and/or an attenuator fitted into the antenna feeder of the receiver. The receiver RF gain must be set at maximum for the S meter to function correctly.

Tests can be conducted at greater distances, but it normally requires a higher gain antenna at the opposite end of the link. Generally, at these greater distances, the S meter readings are much lower but nevertheless provide valuable data if carried out at night when the ionospheric propagation effects are low.

Tests can also be performed using a HF mobile as the other station. The main advantage of using a mobile is that it can be sited at a distance that is more compatible with transmitter power and AUT gain. It is also easier to select a path free of power and telephone lines, which may disturb the radiation pattern.

I had the impression that field strength measurements (and antenna directivity patterns) could only be done in the far field, as described above. See also the ARRL Antenna book [1].

However, I have in the past made similar HF antenna measurements using a signal generator with a short antenna as signal source located in the loft of the house. The AUT was located at the end of the garden about two and a half wavelengths and the polar plots gave a good indication of when the beam was tuned for optimum directivity.

NEAR FIELD TESTS

Most of us do not have the luxury of having enough space to make far field antenna measurements. So can measurements in the near field be valid? What follows is the description of an experiment to see if near field tests have any validity. The tests were carried out on the multi-band quad described in Chapter 7 and is described in the following as the Antenna Under Test (AUT).

The arrangement finally decided on is shown in **Fig 12.13**, and although specifically shown as a method of measuring the directional performance of a quad I see no reason why it should not be used to estimate the performance of any beam antenna.

The AUT is fixed to a 14m high mast, which does not have a rotator. The whole mast is rotated manually and is described in Chapter 10. The field strength meter comprised a FT-990, which has a very good S-meter, and an attenuator.

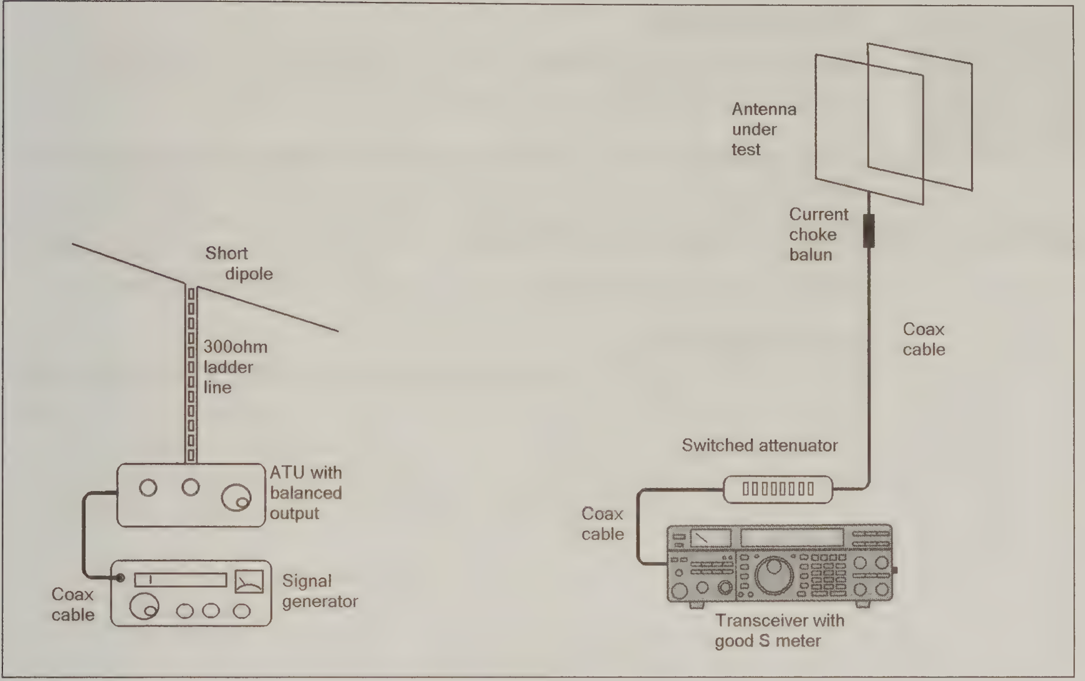


Fig 12.13: Signal generator, ATU and short dipole used to provide a test signal for near field beam directivity measurements. Although not shown, a current balun must be fitted to the coax feed to the AUT.

The signal source is provided by a signal generator and an antenna. The signal source antenna was a horizontally polarized short dipole about 3m long and 2.4m high. It was fed in the centre with balanced slotted line and matched to the signal generator with a balanced ATU. The length and height of the signal source antenna is quite arbitrary and was determined more by convenience than technical considerations.

Because of the relative heights and distances between the AUT and the signal source antenna the measurement angle was just over 30 degrees below the horizontal axis of the AUT.

The quad had been in use only a few weeks before the measurements (or perhaps I should say the assessment of the antenna range) so I had some idea of how the quad was performing.

Because the reflector of the quad was a bit short on 14MHz the F/B on 14.02MHz was non existent while at the top of the band it was reasonable. On the 18 and 21MHz bands it 'seemed OK'.

Because the mast is rotated manually the readings were limited to front-to-back ratio measurements. The initial F/B results were:

14.02MHz 0dB; 14.27MHz 13dB; 18.1MHz 8dB; 21.04MHz 14dB and 21.33MHz 23dB with no noticeable side nulls.

A stub made of slotted line was added to the 14MHz reflector, which increased the F/B to 19dB at 14.2MHz. An extra 200mm of wire was added to the 18MHz reflector, which increased the F/B to around 19dB. The 21MHz band was not readjusted in this test.

Conclusions

While the near field measurement method described is unsuitable for measuring gain, it is appears suited to maximizing the front-to-back ratio of a beam antenna

If you are using an older signal generator, best results are obtained with the signal generator set to AM and the modulator switched on; with the receiver also switched to AM. This makes this test arrangement less susceptible to drift.

Antenna currents on the coax feed line of the AUT make measurements difficult or impossible. A current balun on the line (see Chapter 11) is essential.

REFERENCES

[1] *The ARRL Antenna book*, 20th edition (ARRL).

A1

Appendix 1: Useful data

RESONANT DIPOLE LENGTHS

Table A1 gives the equivalent wavelengths and half wavelengths for given frequencies in metric and imperial units.

Half wavelengths for centre fed dipole or vertical antennas, described in Chapter 2, are also given in metric and imperial units and are calculated using EZNEC.

Most antenna books use the formula:

143/f (MHz) = L (metres) or 468/f (MHz) = L (feet).

This gives a close enough approximation on the higher frequency bands but may be a bit short for the lower bands. For example the formula gives a dipole

Freq:	**λ**		**λ**		**λ/2**		**λ/2**	
MHz	**Dipole**		**Dipole**		**Dipole**		**Dipole**	
	Metres	**Ft/in**	**Metres**	**Ft/in**	**Metres***	**Ft/in***	**Metres #**	**Ft/in #**
1.83	163.82	537'6"	81.91	268'9"	80	262'	-	-
1.9	157.78	517'8"	78.89	259'10"	77	260'7"	-	-
3.52	85.17	279'5"	42.58	139'8"	41.56	135'10"	-	-
3.65	82.13	269'6"	41.07	134'9"	40.08	131.6"	-	-
7.02	42.7	140'1"	21.35	70'0"	20.76	68'2"	-	-
10.125	29.61	97'2"	14.8	48'7"	14.4	47'2"	14.2	46'7"
14.05	21.34	70'0"	10.67	35'0"	10.35	33'11"	10.20	33'5"
14.20	21.11	69'3"	10.55	34'10"	10.24	33'7"	10.09	33'1"
18.1	16.56	54'4"	8.28	27'2"	8.03	26'4"	7.88	25'10"
21.05	14.24	46'9"	7.12	23'5"	6.9	22'8"	6.78	22'3"
21.2	14.14	46'5"	7.07	23'3"	6.86	22'6"	6.73	22'1".
24.94	12.62	39'6"	6.31	19'9"	5.82	19'1"	5.70	18'8"
28.05	10.69	35'0"	5.34	17'6"	5.18	17'0"	5.05	16'7"
28.4	10.56	34'8"	5.28	17'4"	5.1	16'8"	4.99	16'4"
29.5	10.16	33'4"	5.08	16'9"	4.9	16'1"	4.80	15'9"

Table A1: Wavelengths and halfwavelengths, together with resonant lengths for dipoles relative to frequency for the HF bands. (' = ft, " = in). The dipole lengths * are calculated for a wire diameter of 2mm. The dipole lengths # are calculated for a tube diameter of 25mm.

length of 40.6m for 3.52MHz while EZNEC calculates a length of 41.42m for the same frequency.

Remember these lengths are total lengths and the wire has to be cut in half at the centre to connect the coax and that the gap in the centre is part of the whole dipole length.

You also need to be aware that around 160mm (6in) at each end of each half of the dipole elements is required to connect them to the centre insulator and the end insulator.

When a larger diameter conductor is used for the antenna element, the length has to be reduced by an amount known as the K factor (based on the length to diameter ratio).

For example, the calculated length for a dipole for 21.2MHz is 6.86m, or 22'6". If the conductor diameter is increased from 2mm to 25mm (1 in) then the total length should be reduced to 6.73m (22'1").

This can influence the design when making a vertical antenna with the top element of 25mm diameter tube and the lower element(s) of wire. You should use the appropriate column for determining the length. Remember that these figures are for a half-wave antenna. For a ground plane antenna on 21.2MHz the top quarter wave 25mm diameter section should be 6.73/2 = 3.36m. The lower wire radials are 6.86/2 = 3.43m.

In practice tubular elements are best constructed using different diameter telescopic sections. This makes it easy to adjust the length on test for minimum SWR.

METRIC ALUMINIUM TUBE SIZES

Metric size tubing (all inside and outside diameters in whole millimetres), standard on the Continent, are shown in **Table A2**.

OD mm	Wall mm	Weight g/m	OD mm	Wall mm	Weight g/m
6	1	42	28	1.5	336
8	1	60	30	3	687
10	1	76	30	2	484
12	1	93	32	1.5	387
13	1	103	35	2	564
14	1	110	36	1.5	438
16	1	127	40	5	1495
19	1.5	227	40	2	644
20	2	-	40	1.5	489
20	1.5	235	44	1.5	541
22	2	339	45	2	-
22	1.5	261	48	1.5	603
25	2.5	477	50	5	1923
25	2	398	50	2	820
25	1.5	298			

Table A2: Metric-size alloy tubing available in continental Europe. Material F22 (AlMgSo 0.5%). Tensile strength 22kg/mm^2. Standard lengths are 6m.

METRIC/IMPERIAL CONVERSION FACTORS

Metric Unit	Factor	Imperial Unit	Metric Unit	Factor	Imperial Unit
mm	25.4	in	m	0.9144	yard
cm	2.54	in	km	1.609	mile
cm	30.48	ft	gram	28.349	oz
m	0.3048	ft	kg	0.45359	lb
m	0.9144	yard			

Metric Unit = Factor *multiplied* by imperial unit

Metric Unit *divided* by Factor = imperial unit

Table A3: Length and weight conversions

COIL WINDING DATA

Most inductors for tuning on the HF bands are single-layer coils and they are designed as follows.

The inductance of a single-layer coil is given by:

$$L(\mu H) = \frac{D^2 \times T^2}{457.2 \times D + 1016 \times L}$$

where D is the diameter of the coil (millimetres), T is the number of turns and L is the length (millimetres). Alternatively:

$$L(\mu H) = \frac{R2 \times T2}{9 \times R + 10 \times L}$$

where R is the radius of the coil (inches), T is the number of turns and L is the length (inches).

Note that when a ferrite or iron dust core is used, the inductance will be increased by up to twice the value without the core. The choice of which to use depends on frequency. Generally, ferrite cores are used at the lower HF bands and iron dust cores at the higher. At VHF, the iron dust cores are usually coloured purple. Cores need to be moveable for tuning but fixed thereafter and this can be done with a variety of fixatives. A strip of flexible polyurethane foam will do.

Designing inductors with ferrite pot cores

This is a simple matter of taking the factor given by the makers and multiplying it by the square of the number of turns.

Example:

A RM6-S pot core in 3H1 grade ferrite has a 'factor' of 1900 nanohenrys for one turn. Therefore 100 turns will give an inductance of:

100^2 x 1900nH = 10000 x 1900nH = 19mH

There are a large number of different grades of ferrite; for example, the same pot as above is also available in grade 3E4 with a 'factor' of 3300. Manufacturers' literature should be consulted to find these 'factors'.

Voltage ratio (equal Z)	Power ratio	Voltage ratio (equal Z)	Power ratio	+ or - dB
1.000	1.000	1.000	1.000	0
0.989	0.977	1.012	1.023	0.1
0.977	0.995	1.023	1.047	0.2
0.966	0.933	1.035	1.072	0.3
0.955	0.912	1.047	1.096	0.4
0.944	0.891	1.059	1.122	0.5
0.933	0.871	1.072	1.148	0.6
0.923	0.851	1.084	1.175	0.7
0.912	0.832	1.098	1.202	0.8
0.902	0.813	1.109	1.230	0.9
0.891	0.794	1.122	1.259	1.0
0.841	0.708	1.189	1.413	1.5
0.794	0.631	1.259	1.585	2.0
0.750	0.562	1.334	1.778	2.5
0.708	0.501	1.413	1.995	3.0
0.668	0.447	1.496	2.239	3.5
0.631	0.398	1.585	2.512	4.0
0.596	0.335	1.679	2.818	4.5
0.562	0.316	1.778	3.162	5.0
0.531	0.282	1.884	3.548	5.5
0.501	0.251	1.995	3.981	6.0
0.473	0.224	2.113	4.467	6.5
0.447	0.200	2.239	5.012	7.0
0.422	0.178	2.371	5.623	7.5
0.398	0.158	2.512	6.310	8.0
0.376	0.141	2.661	7.079	8.5
0.355	0.126	2.818	7.943	9.0
0.335	0.112	2.985	8.913	9.5
0.316	0.100	3.162	10.00	10
0.282	0.0794	3.550	12.6	11
0.251	0.0631	3.980	15.9	12
0.224	0.0501	4.47	20.0	13
0.200	0.0398	5.01	25.1	14
0.178	0.0316	5.62	31.6	15
0.159	0.0251	6.31	39.8	16
0.141	0.0200	7.08	50.1	17
0.126	0.0159	7.94	63.1	18
0.112	0.0126	8.91	79.4	19
0.100	0.0100	10.0	100.0	20
3.16×10^{-2}	10^{-3}	316	10^{3}	30
10^{-2}	10^{-4}	100	10^{4}	40
3.16×10^{-3}	10^{-5}	316	10^{5}	50

Table A4: Power and voltage ratios

POWER AND VOLTAGE RATIOS IN DECIBELS

Power and voltage ratios are normally expressed in decibels where:

$N(dB) = 10 \log_{10} (P_2/P_1)$ or $N(dB) = 20 \log_{10} (V_2/V_1)$

P_2 and P_1 are power ratios being compared. V_2 and V_1 are voltage ratios being compared; a constant impedance is assumed.

A value in decibels only has absolute meaning if the reference level is stated. The expression dBm and dBW are frequently used for ratios with respect to 1mW and 1W respectively.

A power level of 1mW into 50 or 600Ω has become the standard for comparative purposes and has been given the datum 0dBm. Signal levels above and below this datum are expressed as +dBm and -dBm respectively; they correspond to finite voltage or current levels - not ratios.

0 dBm into 600 ohm resistance corresponds to 0.775V.

0 dBm into 50 ohm resistance corresponds to 0.225V.

A detailed list of power and voltage ratios and their decibel equivalents is shown in **Table A4**.

WIRE GAUGE TABLES

Table A5 (overleaf) shows the metric and imperial dimensions of a range of standard wire (SWG) and American wire guages (AWG).

SOURCES

Antenna modelling programs

EZNEC can be obtained from:

Roy Lewallen, W7EL, PO Box 6658, Beaverton, Oregon 97007, USA.
Visa and Mastercard accepted.

Antenna analysers

In the UK the MFJ-259B and MFJ-269 are available from:

Waters and Stanton plc, 22 Main Road, Hockley, Essex, SS5 4QS.
Tel 01702 206835.

Antennas, antenna materials and tuners

A comprehensive range of coaxial cable, 300 and 450-ohm balanced twin feeders, antenna wire, insulators, dipole centre boxes and coaxial plugs, sockets and adapters are obtainable from:

W H Westlake, West Park, Clawton, Holdsworthy, Devon, EX22 6QN.
Tel: 01409 253758.

Table A5: Wire gauges

	SWG		*AWG*	
Wire No	**in**	**mm**	**in**	**mm**
0000	0.40	10.16	0.460	11.68
000	0.372	9.45	0.409	10.41
00	0.348	8.84	0.365	9.27
0	0.324	8.23	0.325	8.25
1	0.300	7.62	0.289	7.35
2	7.276	7.01	0.258	6.54
3	0.252	6.40	0.229	5.83
4	0.232	5.89	0.204	5.19
5	0.212	5.38	0.182	4.62
6	0.192	4.88	0.162	4.11
7	0.176	4.47	0.144	3.66
8	0.160	4.06	0.128	3.26
9	0.144	3.66	0.144	2.90
10	0.128	3.25	0.102	2.59
11	0.116	2.95	0.091	2.30
12	0.104	2.64	0.081	2.05
13	0.092	2.34	0.072	1.83
14	0.081	2.03	0.064	1.63
15	0.072	1.83	0.057	1.45
16	0.064	1.63	0.051	1.29
17	0.056	1.42	0.045	1.15
18	0.048	1.22	0.040	1.02
19	0.040	1.02	0.036	0.91
20	0.036	0.92	0.032	0.81
21	0.032	0.81	0.028	0.72
22	0.028	0.71	0.025	0.64
23	0.024	0.61	0.023	0.57
24	0.023	0.56	0.020	0.51
25	0.020	0.51	0.018	0.45
26	0.018	0.46	0.016	0.40
27	0.016	0.41	0.014	0.36
28	0.014	0.38	0.013	0.32
29	0.013	0.35	0.011	0.29
30	0.012	0.305	0.010	0.25
31	0.011	0.29	0.009	0.23
32	0.0106	0.27	0.008	0.20
33	0.010	0.254	0.007	0.18
34	0.009	0.229	0.0063	0.16
35	0.008	0.203	0.0056	0.14
36	0.007	0.178	0.0050	0.13
37	0.0067	0.17	0.0044	0.11
38	0.006	0.15	0.0040	0.10
39	0.005	0.127	0.0035	0.08

SWG = Standard Wire Gauge

AWG = American Wire Gauge

The following UK distributors supply various components, such as high power variable capacitors, meters, switches and plugs.

Maplin MPS, PO Box 777, Raleigh, Essex, SS68LU.
Tel 01702 556001.

Nevada Radio, 189 London Road, North End, Portsmouth, Hants PO2 9AE.
Tel 01705 662145.

Ferrite cores such as the T-200 can be obtained from:

J A B Electronic Components, PO Box 5774, Birmingham B44 8PJ.
www.jabdog.com

A high power variable capacitor kit, dummy load kit and HF-VHF SWR/RF wattmeter kit is available from:

Waters and Stanton plc, 22 Main Road, Hockley, Essex, SS5 4QS.
Tel 01702 206835.

IONOSPHERIC PROPAGATION INFORMATION

The Sunspot Index Data Centre in Brussels now prepares the numbers from information supplied by a number of observatories. They appear in DX propagation information available from a wide variety of sources, including the RSGB.

The *GB2RS* weekly news broadcasts from the RSGB give details of the Solar Flux, A and K indices described in Chapter 1 of this book. This propagation information is also available on the Radio Society of Great Britain web site http//:www.rsgb.org.

More immediate daily information can be found on:
http://dx.qsl.net.propagation

Appendix 2: Glossary of terms

This glossary provides a list of terms, used frequently in amateur radio conversation and literature about antennas, and a list of common abbreviations. It is based on the Glossary from the *ARRL Antenna Book* and is given here with their permission.

With each item is a brief definition of the term. Some of the terms given here are discussed more thoroughly in the text of this book, and may be located by using the Contents List or the Index.

A index: A measure of the geomagnetic disturbance caused by the sun on a scale 0 to 400.

Actual ground: The point within the earth's surface where effective ground conductivity exists. The depth for this point varies with frequency and the condition of the soil.

Antenna: An electrical conductor or array of conductors that radiates signal energy (transmitting) or collects signal energy (receiving).

ATU (Antenna Tuning Unit): A device containing variable reactances (and perhaps a balun). It is connected between the transmitter and the feed point of an antenna system, and adjusted to 'tune' or resonate the system to the operating frequency. Also known as an ASTU (Antenna System Tuning Unit). In the USA an ATU is normally referred to as a Transmatch.

Aperture, effective: An area enclosing an antenna, on which it is convenient to make calculations of field strength and antenna gain. Sometimes referred to as the 'capture area'.

Apex: The feed-point region of a V type of antenna.

Apex angle: The included angle between the wires of a V, an inverted V dipole, and similar antennas, or the included angle between the two imaginary lines touching the element tips of a log periodic array.

Array: A group of radiating elements spaced some distance apart, with the current in each element having a particular amplitude and phase to increase the gain.

Balanced line: A symmetrical two-conductor feed line that has uniform voltage and current distribution along its length.

Balun: A device for feeding a balanced load with an unbalanced line, or vice versa. May be a form of choke, or a transformer that provides a specific impedance transformation (including 1:1). Often used in antenna systems to interface a coaxial transmission line to the feed point of a balanced antenna, such as a dipole.

Bandwidth: The current taken by a resonant antenna, and hence the radiation, falls off as the frequency is varied away from resonance. There will be two frequencies, one above and one below resonance, at which the power will be reduced by half. The difference between these frequencies is termed the bandwidth of the antenna.

Base loading: A lumped reactance that is inserted at the base (ground end) of a vertical antenna to resonate the antenna.

Bazooka: A transmission line balancer. It is a quarter-wave conductive sleeve (tubing or flexible shielding) placed at the feed point of a centre-fed element and grounded to the shield braid of the coaxial feed line at the end of the sleeve farthest from the feed point. It permits the use of unbalanced feed line with balanced feed antennas.

Beamwidth: Related to directive antennas. The width, in degrees, of the major lobe between the two directions at which the relative radiated power is equal to one half its value at the peak of the lobe (half power = -3dB).

Broadside array: A broadside source has maximum radiation normal to its axis. A representative broadside array is a colinear array of horizontal array dipoles.

Bridge: A circuit with two or more ports that is used in measurements of impedance, resistance or standing waves in an antenna system. When the bridge is adjusted for a balanced condition, the unknown factor can be determined by reading its value on a calibrated scale or meter.

Capacitance hat: A conductor of large surface area that is connected at the high-impedance end of an antenna to effectively increase the electrical length. It is sometimes mounted directly above a loading coil to reduce the required inductance for establishing resonance. It usually takes the form of a series of wheel spokes or a solid circular disc.

Capture area: See Aperture.

Centre fed: Transmission-line connection at the electrical centre of an antenna radiator.

Centre loading: A scheme for inserting inductive reactance (coil) at or near the centre of an antenna element for the purpose of lowering its resonant frequency. Used with elements that are less than a quarter wavelength at the operating frequency.

Coax: See Coaxial cable.

Coaxial cable: Any of the coaxial transmission lines that have the outer shield (solid or braided) on the same axis as the inner or centre conductor. The insulating material can be air, helium or solid-dielectric compounds.

Collinear array: A linear array of radiating elements (usually dipoles) with their axes arranged in a straight line. Popular at VHF and above.

Common mode signal: signal of similar amplitude and phase on both wires of a transmission line or input to an amplifier (as opposed to the normal anti-phase signal)

Conductor: A metal body such as tubing, rod or wire that permits current to travel continuously along its length.

Counterpoise: A wire or group of wires mounted close to ground, but insulated from ground, to form a low-impedance, high-capacitance path to ground. Used at MF and HF to provide an RF ground for an antenna. Also see ground plane.

Current loop: A point of current maximum (antinode) on an antenna.

Current node: A point of current minimum on an antenna.

D layer: The lowest of the ionised layers of the ionosphere.

Decibel: A logarithmic power ratio, abbreviated dB. May also represent a voltage or current ratio if the voltages or currents are measured across (or through) identical impedances. Suffixes to the abbreviation indicate references: dBi, isotropic radiator; dBd, dipole; dBm, milliwatt; dBW, watt.

Delta loop: A full-wave loop shaped like a triangle or delta.

Delta match: Centre-feed technique used with radiators that are not split at the centre. The feed line is fanned near the radiator centre and connected to the radiator symmetrically. The fanned area is delta shaped.

Dielectrics: Various insulating materials used in antenna systems, such as found in insulators and transmission lines.

Dipole: An antenna that is split at the exact centre for connection to a feed line. A resonant dipole is usually a half wavelength long. A multiband dipole is usually fed with tuned feeders.

Directivity: The property of an antenna that concentrates the radiated energy to form one or more major lobes.

Director: A conductor placed in front of a driven element to cause directivity. Frequently used singly or in multiples with Yagi or cubical-quad beam antennas.

Doublet: A dipole.

Driven array: An array of antenna elements, which are all driven or excited by means of a transmission line, usually to achieve directivity.

Driven element: {1} An element connected to the transmitter/receiver via a transmission line. {2} A radiator element of an antenna system to which the transmission line is connected.

Dummy load: A resistor used to provide a non-radiating substitute for an antenna for testing transmitters or transmission line test equipment.

E layer: The ionospheric layer nearest earth from which radio signals can be reflected to a distant point, generally a maximum of 2000km (1250 miles).

E plane: Related to a linearly polarised antenna, the plane containing the electric field vector of the antenna and its direction of maximum radiation. For terrestrial antenna systems, the direction of the E plane is also taken as the polarisation of the antenna. The E plane is at right angles to the H plane.

Effective radiated power (ERP): For a lossy low frequency antenna the power dissipated in the radiation resistance when other losses have been taken into consideration. For omnidirectional vertical antennas the more common term is ERMP (effective radiated monopole radiated power). For HF, and particularly VHF/UHF, the power supplied to the antenna multiplied by the relative gain of the antenna in the direction of maximum radiation. The term EIRP (effective Isotropic radiated power) is also used taking the gain of the antenna into account as referenced to isotropic.

Efficiency: The ratio of useful output power to input power, determined in antenna systems by losses in the system, including in nearby objects.

Elements: The conductive parts of an antenna system that determine the antenna characteristics. For example, the reflector, driven element and directors of a Yagi antenna.

End effect: A condition caused by capacitance at the ends of an antenna element. Insulators and related support wires contribute to this capacitance and lower the resonant frequency of the antenna. The effect increases with conductor diameter and must be considered when cutting an antenna element to length.

Endfed: An end-fed antenna is one to which power is applied at one end, rather than at some point between the ends.

Endfire antenna: An endfire source has maximum radiation along the linear axis; a representative endfire array is the Yagi antenna.

EZNEC: Computer program for calculating the performance of an antenna, see Appendix.

F layer: The ionospheric layer that lies above the E layer. Radio waves can be refracted from it to provide communications distances of several thousand miles by means of single- or double-hop skip.

Feed impedance: The impedance of an antenna at the point where it is connected to the feeder.

Feed line: See Feeders.

Feed point: The point where the feeder is connected to the antenna element

Feeders: Transmission lines of assorted types that are used to route RF power from a transmitter to an antenna, or from an antenna to a receiver.

Field strength: The intensity of a radio wave as measured at a point some distance from the antenna. This measurement is usually made in microvolts per metre.

Free space: A term used where antenna performance calculations are simplified by ignoring the effect of ground.

Front to back: The ratio of the radiated power off the front and back of a directive antenna. For example, a dipole would have a ratio of 1, which is equivalent to 0 dB.

Front to side: The ratio of radiated power between the major lobe and that 90° off the front of a directive antenna.

Gain: The increase in effective radiated power in the desired direction of the major lobe compared with a reference, such as a dipole or an isotropic source.

Gamma match: A matching system used with driven antenna elements to effect a match between the transmission line and the feed point of the antenna. It consists of a series capacitor and an arm that is mounted close to the driven element and in parallel with it near the feed point.

Ground plane: A system of conductors placed beneath an elevated antenna to serve as an earth ground. Also see Counterpoise.

Ground screen: A wire mesh counterpoise.

Ground wave: Radio waves that travel along the earth's surface.

H plane: Related to a linearly polarised antenna. The plane containing the magnetic field vector of an antenna and its direction of maximum radiation. The H plane is at right angles to the E plane.

Hairpin match: A U-shaped conductor that is connected to the two inner ends of a split dipole for the purpose of creating an impedance match to a balanced feeder.

Harmonic antenna: An antenna that will operate on its fundamental frequency and the harmonics of the fundamental frequency for which it is designed. A 7MHz dipole operating on 21MHz is an example.

Helical: A helically wound antenna, one that consists of a spiral conductor. If it has a very large winding length to diameter, it provides broadside radiation. If the length-to-diameter ratio is small, it will operate in the axial mode and radiate off the end opposite the feed point. The polarization will be circular for the axial mode, with left or right circularity, depending on whether the helix is wound clockwise or counterclockwise.

Impedance: The ohmic value of an antenna feed point, matching section or transmission line. An impedance may contain a reactance as well as a resistance component.

Inverted V: Any antenna erected in the form of an upside-down V; normally with the feed point at the apex.

Isotropic: An imaginary or hypothetical point-source antenna that radiates equal power in all directions. It is used as a reference for the directive characteristics of actual antennas.

K index: A measure of the geomagnetic disturbance caused by the sun on a scale 0 to 9.

Lambda: Greek symbol λ used to represent a wavelength with reference to electrical dimensions.

Line loss: The power lost in a transmission line, usually expressed in decibels.

Line of sight: Transmission path of a wave that travels directly from the transmitting antenna to the receiving antenna.

Litz wire: Stranded wire with individual strands insulated from each other. Used to reduce RF losses in lower frequency inductors.

Load: The electrical entity to which power is delivered. The antenna system is a load for the transmitter.

Loading: The process of a transferring power from its source to a load. The effect a load has on a power source.

Lobe: A defined field of energy that radiates from a directive antenna.

Log periodic antenna: A broadband directive antenna that has a structural format causing its impedance and radiation characteristics to repeat periodically as the logarithm of frequency.

Long wire: A wire antenna that is one wavelength or greater in electrical length. When two or more wavelengths long it provides gain and a multilobe radiation pattern. When terminated at one end it becomes essentially unidirectional off that end.

Marconi antenna: A shunt-fed monopole operated against ground or a radial system.

Matching: The process of effecting an impedance match between two electrical circuits of unlike impedance. One example is matching a transmission line to the feed point of an antenna. Maximum power transfer to the load (antenna system) will occur when a matched condition exists.

Monopole: Literally, one pole, such as a vertical radiator operated against the earth or a counterpoise.

Null: A condition during which an electrical unit is at a minimum. The null in an antenna radiation pattern is that point in the 360-degree pattern where a minimum in field intensity is observed. An impedance bridge is said to be 'nulled' when it has been brought into balance, with a null in the current flowing through the bridge arm.

Open-wire line: A type of transmission line that resembles a ladder, sometimes called 'ladder line'. Consists of parallel, symmetrical wires with insulating spacers at regular intervals to maintain the line spacing. The dielectric is principally air, making it a low-loss type of line.

Parasitic element: An element, which is not connected directly to the transmitter/receiver via a transmission line, but receives its energy by the coupling due to the proximity of other elements.

Parasitic array: A directive antenna that has a driven element and at least one independent parasitic element (director or reflector), or a combination of both. A Yagi antenna is one example of a parasitic array.

Phasing lines: Sections of transmission line that are used to ensure the correct phase relationship between the elements of a driven array, or between bays of an array of antennas. Also used to effect impedance transformations while maintaining the desired phase.

Polarisation: The sense of the wave radiated by an antenna, by convention is aligned with the E-field of an electromagnetic wave. This can be horizontal, vertical, elliptical or circular (1eft or right hand circularity), depending on the design and application.

Q section: Term used in reference to transmission-line matching transformers and phasing lines.

Quad: A parasitic array using rectangular or diamond shaped full-wave wire loop elements. Often called the 'cubical quad'.

Radiation pattern: The radiation characteristics of an antenna as a function of space co-ordinates. Normally, the pattern is measured in the far-field region and is represented graphically.

Radiation resistance: The resistive component of an antenna that converts all RF power supplied to it from a transmitter to radiation. In practice there are losses in the antenna which convert some of the transmit power to heat.

Radiator: A discrete conductor that radiates RF energy in an antenna system.

Random wire: A random length of wire used as an antenna and fed at one end and resonated by means of an ATU.

Reflector: A parasitic antenna element or a metal assembly that is located behind the driven element to enhance forward directivity. Hillsides and large man-made structures such as buildings and towers may act as reflectors.

Refraction: Process by which a radio wave is bent and returned to earth from an ionospheric layer or other medium after striking the medium.

Resonator: In antenna terminology, a loading assembly consisting of a coil and a short radiator section. Used to lower the resonant frequency of an antenna, usually a vertical or a mobile whip.

Shunt feed: A method of feeding an antenna driven element with a parallel conductor mounted adjacent to a low impedance point on the radiator. Frequently used with grounded quarter-wave vertical antennas to provide an impedance match to the feeder. Series feed is used when the base of the vertical is insulated from ground.

Solar flux: A measure of solar activity, on a scale 66 to 300, obtained by measuring the noise from the sun on 2800MHz.

Stacking: The process of placing similar directive antennas atop or beside one another, forming a 'stacked array'. Stacking provides more gain or directivity than a single antenna.

Stub: A section of transmission line used to tune an antenna element to resonance or to aid in obtaining an impedance match.

SWR: Static waveform on a transmission line due to mismatch. The ratio of the voltage or current maximum to minimum of the static wave is termed standing-wave ratio. The degree of mismatch on a transmission line can be determined using an SWR meter.

Tank Circuit: A parallel tuned circuit in a power amplifier or ATU.

T match: Method for matching a transmission-line to an unbroken driven element. Attached at the electrical centre of the driven element in a T-shaped manner. In effect it is a double gamma match.

Top loading: Addition of a reactance (usually a capacitance hat) at the end of an antenna element opposite the feed point to increase the electrical length of the radiator.

Transmatch: See ATU.

Trap: Parallel L-C network inserted in an antenna element to provide multiband operation with a single conductor.

Tuned Feeder: A transmission line that provides a designed degree of impedance transformation, in addition to its primary purpose of conveying RF energy with minimal radiation.

Velocity factor: The ratio of the velocity of radio wave propagation in a dielectric medium to that in free space. When cutting a transmission line to a specific electrical length, the velocity factor of the particular line must be taken into account.

VSWR: Voltage standing-wave ratio. See SWR.

WARC bands: Frequency bands 10.100 - 10.150MHz, 18.068 - 18.168MHz and 24.890 - 24.990MHz .

Wave: A disturbance or variation that is a function of time or space, or both, transferring energy progressively from point to point. A radio wave, for example.

Wave angle: The angle above the horizon of a radio wave as it is launched from or received by an antenna.

Wavefront: A surface that is a locus of all the points having the same phase at a given instant in time.

Yagi: A directive, gain type of antenna that utilises a number of parasitic directors and a reflector. Named after one of the two Japanese inventors (Yagi and Uda).

Z match: A multi-band ATU derived from the link-coupled PA tank circuit.

Zepp antenna: A half-wave wire antenna that operates on its fundamental and harmonics. It is fed at one end by means of open-wire feeders. The name evolved from its popularity as an antenna on Zeppelins.

ABBREVIATIONS

A	ampere
ac	alternating current
AM	amplitude modulation
ARRL	American Radio Relay League
AWG	American wire gauge
az	el azimuth elevation
balun	balanced to unbalanced
BC	broadcast
BCI	broadcast interference
BW	bandwidth
cm	centimetre
coax	coaxial cable
CT	centre tap
CW	continuous wave
dB	decibel
dBd	decibels referenced to a dipole
dBi	decibels referenced to isotropic
dBm	decibels referenced to one milliwatt
dBW	decibels referenced to one watt

DC	direct current
deg	degree
DF	direction finding
DPDT	double pole, double throw
DPST	double pole, single throw
DVM	digital voltmeter
DX	long distance communication
E	ionospheric layer
E	electric field
EIRP	effective isotropic radiated power
ELF	extremely low frequency
EMC	electromagnetic compatibility
EME	Earth-Moon-Earth
EMF	electromotive force
ERP	effective radiated power
f	frequency
F	ionospheric layer
F	farad
F/B	front to back (ratio)
FM	frequency modulation
ft	foot or feet (unit of length)
Fl	ionospheric layer
F2	ionospheric layer
GDO	grid- or gate-dip oscillator
GHz	Gigahertz
Gnd	ground
H	magnetic field
H	henry
HF	high frequency (3-30 MHz)
Hz	Hertz (unit of frequency)
I	current
ID	inside diameter
IEEE	Institute of Electrical and Electronic Engineers
IEE	Institution of Electrical Engineers
in.	inch
j	vector notation
kHz	kilohertz
km	kilometre
kW	kilowatt
kΩ	kilohm

L	inductance
lb	pound (unit of mass)
LF	low frequency (30-300kHz)
LHCP	left-hand circular polarisation
ln	natural logarithm log - common logarithm
LP	log periodic
LPDA	log periodic dipole array
LPVA	log periodic V array
LUF	lowest usable frequency
m	metre (unit of length)
mA	milliampere
max	maximum
MDF	medium density fibreboard
MF	medium frequency (0.3-3 MHz)
mH	millihenry
MHz	Megahertz
min	minimum
mm	millimeter
ms	millisecond
mS	millisiemen
MUF	maximum usable frequency
mW	milliwatt
MΩ	Megohm
NBS	National Bureau of Standards
NC	no connection, normally closed
nF	nanofarad
NiCd	nickel cadmium
NO	normally open
OD	outside diameter
p-p	peak to peak
PC	printed circuit
PEP	peak envelope power
pF	picofarad
Q	Tuned circuit figure of merit
R	resistance, resistor
RF	radio frequency
RFC	radio frequency choke
RFI	radio frequency interference
RHCP	right-hand circular polarisation
RLC	resistance-inductance-capacitance
RMS	root mean square

RSGB	Radio Society of Great Britain
s	second
S	siemen
S/NR	signal-to-noise ratio
SINAD	signal-to-noise and distortion
SPDT	single pole, double throw
SPST	single pole, single throw
SWR	standing wave ratio
tpi	turns per inch
TR	transmit-receive
TVI	television interference
UHF	ultra-high frequency (300-3000MHz)
UTC	Universal Time, Coordinated
V	volt
VF	velocity factor
VHF	very high frequency (30-300MHz)
VLF	very low frequency (3-30kHz)
VOM	volt-ohm meter
VSWR	voltage standing-wave ratio
VTVM	vacuum-tube voltmeter
W	watt
WARC	World Administrative Radio Conference
WPM	words per minute
X	reactance
Z	impedance

Other symbols and Greek letters

°	degrees
λ	wavelength
µ	permeability
µF	microfarad
µH	microhenry
µV	microvolt
Ω	ohm
π	3.14159

A3

Appendix 3: Safety and maintenance

SAFETY

Working on antennas

Working with antennas often means working at some height above the ground. All antenna work, particularly on HF antennas, involves the use of a ladder or a stepladder. I am personally aware of more accidents due to misuse of ladders and stepladders than any other cause.

It is important that a ladder is set at a safe angle and fixed as firmly in place as the situation will allow. A stepladder should be fully open with all four feet in contact with the ground. This can be difficult on uneven ground but wooden or concrete slabs can be used as packing under one or two of the stepladder legs.

If you are fixing an antenna to a chimney or the apex of a roof, don't even think about going on to a roof without a crawling ladder. These can be hired from a tool hire company.

If you are not confident about your abilities as a steeplejack then you can assemble an antenna on the ground and then employ a television antenna erection company to fix it in place.

When working at any height above the ground, work slowly and methodically, always considering the implication of the next move. While climbing and carrying an antenna you could lose your balance if the antenna elements are snagged in tree branches, ladders or any part of the mast or building.

When working on antenna or antenna support systems on a high rise block balcony or rooftop pay attention to safety details. Not only should you not put yourself in danger; if you drop the smallest of tools or antenna fittings they can have a damaging velocity by the time they reach the ground. Tie all tools and fittings loosely together, with strong thin nylon cord, so that movement is not impeded, but ensuring they don't fall far if dropped.

Many accidents are caused by trying to rush the work, possibly because it is getting dark and the job must be finished, or trying to obtain maximum antenna optimisation just before a contest in a few hours time. An accident results in this work not being done anyway.

AC mains supplies

Overhead AC supply cables are rare in backyard antenna locations. However, if you are unfortunate enough to have these obstructions, it is very important that antennas are positioned so that they cannot possibly come in contact with them.

Never erect an antenna and mast that could possibly come in contact with electric power lines, even in the event of structural failure of the mast or antenna

It is sometimes necessary to use power tools or test equipment powered from the AC mains supply. Never use AC mains powered equipment in wet weather or if the ground is wet. Always use an earth leakage trip. This device is simply connected into the extension lead at the AC mains supply socket. I have found an rechargeable battery operated electric drill an excellent investment for the antenna constructor.

Antenna masts

Steel mast sections can be very heavy. Ensure that adequate lifting tackle and a gin pole is available. Always stop to consider the implications of the next move, particularly when dealing with heavy sections of metal.

MAINTENANCE

All fixings, including U-bolts and hose clamps should be given a protective layer of grease. Although this procedure is a bit messy it enables nuts to be removed from bolts after being exposed to the elements for years. It also minimises the possibility of antenna support failure due to corrosion.

All metal surfaces forming an electrical connection should also be protected this way. This is particularly important where copper wire is fixed to the aluminium on the elements. The effect of clamping dissimilar metals can result is a film of oxide on the joints within a few weeks of construction, resulting in antenna inefficiency and the danger of TVI if this protection is not carried out.

The end, or any joints, of the coaxial cable should be sealed against the ingress of moisture. How this is done depends on the degree of permanency required. I use a general-purpose grease normally used for wheel bearings. This keeps PL-259 plugs and sockets, or the screw connectors free from corrosion. It also appears to prevent moisture entering the coaxial cable.

Self-amalgamating tape or silicone rubber sealant can be used for sealing the end of coaxial cable if a more permanent solution to waterproofing is required.

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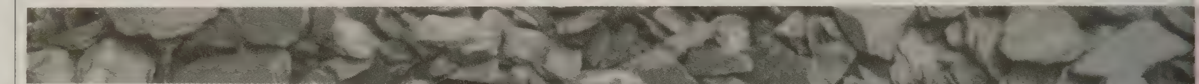

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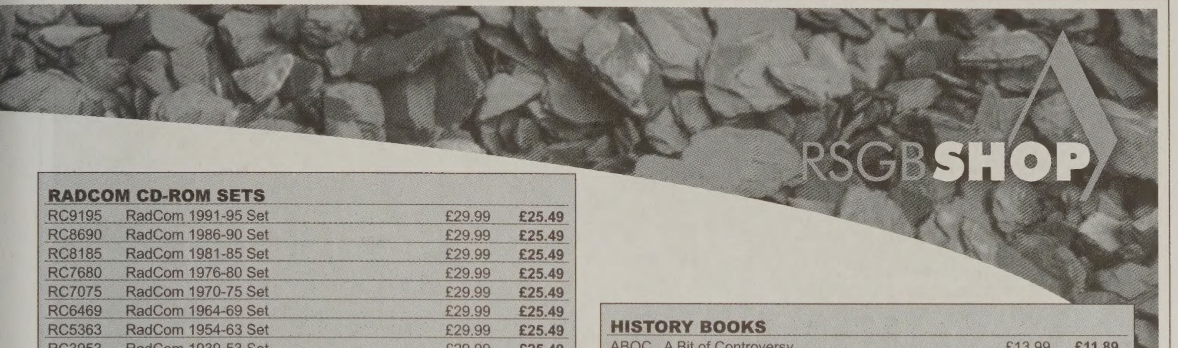

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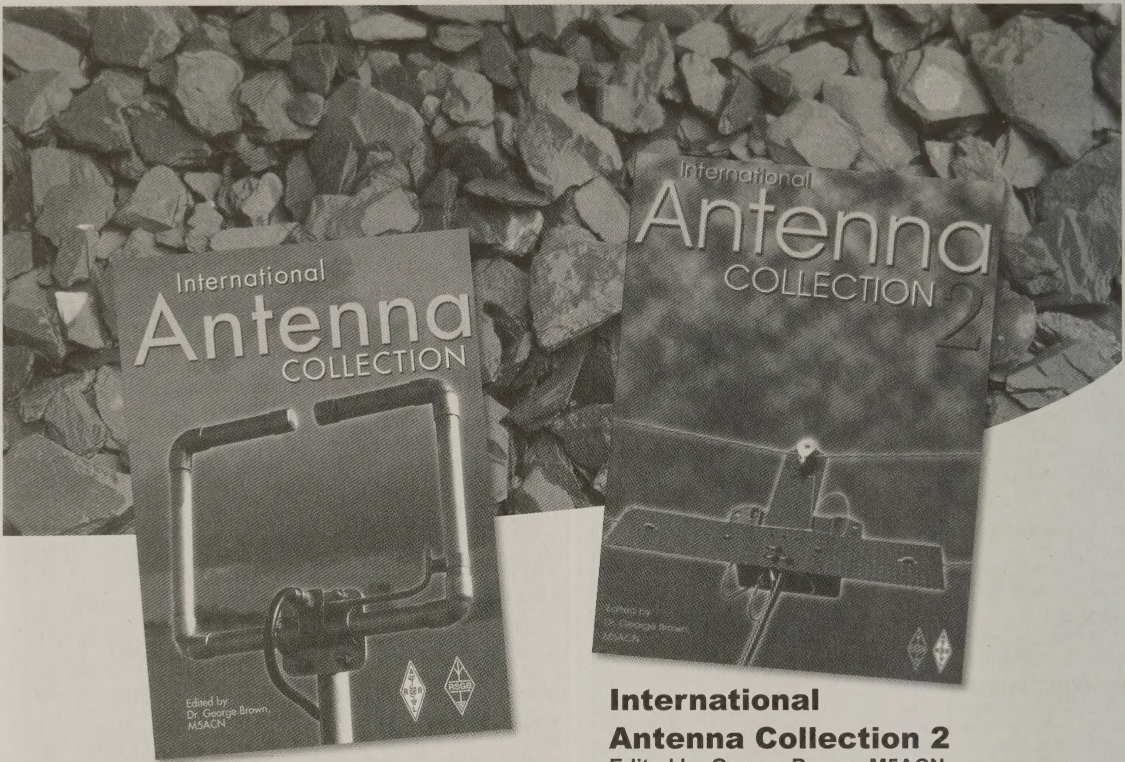

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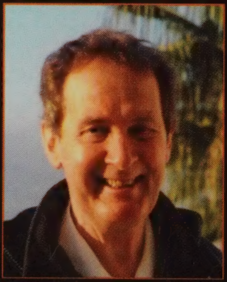

Peter first obtained an amateur radio licence in 1956, as G3LDO. He served with the RAF, where his tours of duty took him to East Africa, where he operated with call signs VQ4HX, VQ3HX and VQ1HX. After leaving the RAF, Peter operated as 9L1HX in Sierra Leone where he was working as a police communications officer and then a mining engineer. Following this Peter took up a career as a technical author, later becoming the Technical Editor of the Radio Society of Great Britain Journal *RadCom* before retiring in 1997.

Peter is the author of several books including The *Antenna Experimenter's Guide*, The *Low Frequency Experimenter's Handbook* and *Backyard Antennas*. His work has been included in many other books and magazines including the ARRL *Antenna Compendium* series, *QST* and *QEX* and he is the 'Antennas' columnist for *RadCom*.

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